STRESS ANALYSIS ON ENGINE BLOCK CONSIDERING THERMAL EFFECT

MUHAMMAD RAZIQ BIN ABU SAMAH

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DECLARATION

I declare that this project report entitled "Stress Analysis On Engine Block Considering Thermal Effect" is the result of my own work except as cited in the references.

Signature	:	....
Name	:	MUHAMMAD RAZIQ BIN ABU SAMAH
Date	:	28 JUNE 2019

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 with Honours.

Signature :. ....

Name of Supervisor : ....

Date : ....

DEDICATION

This project and research work is dedicated to my beloved parents for their enthusiastic caring throughout my life, my loving siblings, my supervisor and also all of my fellow friends for their encouragement and love.

ABSTRACT

A very complex demand from customer, laws and business requirements will have to be met by future design of internal combustion engines for light duty applications. Customers expect further improvements in durability, reliability, driving performance, fuel economy and ownership costs. Laws requirements focus on substantial reductions in emissions and fuel consumption. In order to maintain or having a better grow business in competitive environment, additional cost reductions in manufacturing will be essential. The focus for future development of gasoline engines will be on improvements in fuel economy combustion systems and reduction losses in part load operation. A combined experimental and analytical approach was followed in this study of stress and temperature on cylinder block under steady-state operation. First, experimental studies were performed to measure temperatures and stresses under stable conditions of operation. In addition, the value of stress at the point can be obtained by placing high temperature strain gauges on the engine block. Subsequently, the detailed stress distributions on the engine block were predicted by a finite element analysis. A comparison of the predicted stress on the analysis of finite elements were being compared with the experiment's stress value.

ABSTRAK

Keperluan pelanggan, perundangan dan perniagaan yang sangat kompleks perlu dipenuhi oleh enjin pembakaran dalaman masa hadapan untuk aplikasi tugas ringan. Pelanggan mengharapkan penambahbaikan selanjutnya dalam ketahanan, kebolehpercayaan, prestasi memandu, ekonomi bahan api dan kos pemilikan. Keperluan undang-undang memberi tumpuan kepada pengurangan besar dalam pengeluaran dan penggunaan bahan bakar. Untuk mengekalkan atau mengembangkan perniagaan dengan persekitaran yang sangat kompetitif, pengurangan kos tambahan dalam pembuatan akan menjadi penting. Tumpuan untuk pembangunan masa depan enjin petrol akan meningkatkan ekonomi bahan api melalui sistem pembakaran yang lebih baik dan mengurangkan kerugian dalam operasi beban bahagian. Pendekatan percubaan dan analitik gabungan diikuti dalam kerja ini untuk mengkaji tekanan dan suhu pada blok silinder di bawah operasi keadaan mantap. Pertama, kajian eksperimen dilakukan untuk mengukur suhu dan tekanan di bawah keadaan operasi yang stabil. Di samping itu, nilai tegasan pada titik boleh diperolehi dengan meletakkan tegangan suhu tinggi pada blok enjin. Selanjutnya, pengedaran tegasan terperinci pada blok enjin diprediksi oleh analisis unsur terhingga. Perbandingan tekanan yang diramalkan mengenai analisis unsur terhingga berbanding dengan nilai tekanan eksperimen.

ACKNOWLEDGEMENT

It is such a great pleasure and gratitude to acknowledge people whose guidance and encouragement contribute hugely towards the completion of my final year project.

First and foremost, I am grateful to the God as He gave me the opportunities to complete this thesis. Next, a huge thanks to my supervisor, Ir. Dr. Mohd Shukri Bin Yob, for being supportive in coaching and sharing knowledge with me, guiding me throughout two semester. In preparing this thesis, there were many people that give a hand towards my understanding and perspective which were the lecturers, seniors and my friends. Particularly, I want to convey my appreciation to all of them for all the guidance and advices.

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LIST OF ABBREVIATION

ICE	-	Internal Combustion Engine
EXE	-	External Combustion Engine
TDC	-	Top Dead Center
BDC	-	Bottom Dead Center
RPM	-	Revolution per Minute
CATIA	-	Computer Aided Three-dimensional Interactive Application
ANSYS	-	Analysis System
FEA	-	Finite Element Analysis
IGES	-	Initial Graphics Exchange Specification
STP	-	Standard Exchange Product

CHAPTER 1

INTRODUCTION

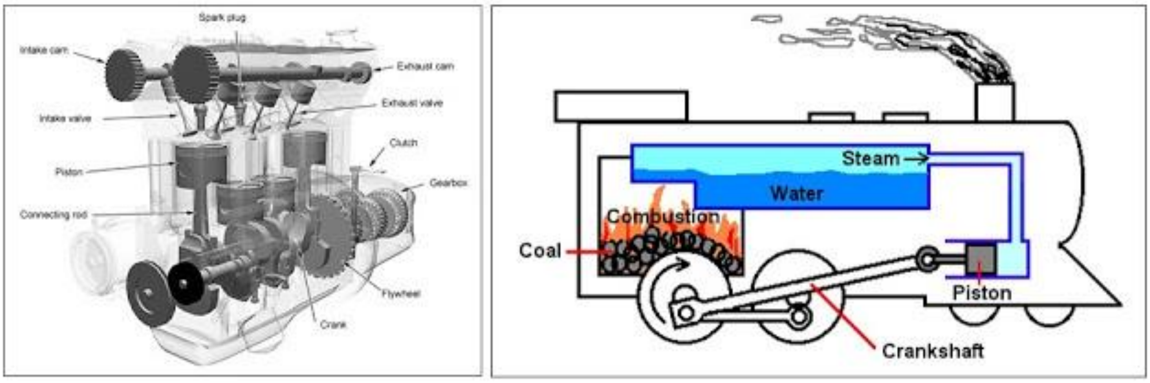
1.1 Background

A motorcycle often called a bike, motorbike or cycle is a two, three-wheel motor vehicle. Nowadays, there have a four-wheeled motor vehicle according to the needs and modern invention. The design of the motorcycle depends on the needs such as travel, commuting, cruising, sport and off-road riding. In the other word, there are three type of motorcycle which is street, off-road and dual purpose. Each type of purpose provides either specialized advantages and each design creates a different position of riding.

The transmission is a mechanical component designed to transmit power from the engine to the drive axle which make the wheels drive the vehicle. There are three parts in the transmission which are gear, clutch and drive system. By carrying the gear ratio, the transmission can control the levels of power and speed of the wheels. For example, the transmission provides more power and less speed in a short range but it provides less power and high speed in a long range. Indirectly, it reduces the load on the engine and fuel economy while increasing the speed of the vehicle. There are two type of transmission which are automatic transmission and manual transmission.

In term of motorcycle, there must be have an engine. The engine is the heart of the motorcycle. There are two type that are mostly used around the world which is four strokes and two strokes internal combustion engine (ICE). A four strokes engine required the piston complete four separate stroke while turning the crankshaft. The four separate strokes are intake, compression, ignition and exhaust. Different with two strokes engine, the power cycle completes with up and down movement of the piston during the only one crankshaft revolution. The end of the combustion stroke and the beginning of the compression stroke happen at the same time with the intake and exhaust function occurring simultaneously. Two strokes engine have a greatly reduced number of moving parts, so it can be more compact compared to four strokes engine. But, four strokes engine is more fuel economy due to more complete combustion of intake charge in four strokes engine.

The most vital components for the engine are engine block and cylinder head where the combustion process occur inside the components. There are two type of engine which are external combustion engine and internal combustion engine (Pankaj Mishra, 2016). Basically, the ICE is an engine in which a fuel (usually fossil fuel) is combusted in a combustion chamber with an oxidizer (usually air). The expansion of the high-temperature and pressure gasses produced by combustion in an ICE applies direct force to some engine components such as pistons, turbine blades or a nozzle (Mahesh Kumar, 2016). The ICE is quite different from external combustion engine (ECE), such as Sterling engine or steam, where the energy is delivered to a non-combustion product working fluid. Air, hot water, pressurized water or even liquid sodium, heat and some kind of boiler can be working fluids. Figure 1.1 below shows the example of ICE and ECE.



Internal Combustion Engine　　　External Combustion Engine

Figure 1.1: The two type of engine (Pankaj Mishra, 2016)

The cylinder block is the basic framework of a engine. Piston ring, pistons and connecting rod was supported and holds by the cylinder block. The cylinder is a large hole inside the block of the cylinder, surrounded by the wall of the cylinder. Under combustion pressure, the piston travels quickly back and forth in the cylinder. The wall of the cylinder guides the moving piston, receives the pressure of combustion and transmit heat of combustion outside the engine. During operation, the cylinder wall must maintain a precise roundness and straightness of μm order(Hiroshi Yamagata, 2005). Typically, the cylinder bore wall experiences local wear at the top dead center (TDC) point where the oil film most likely fails and scratches along the piston's travel direction. Figure 1.2 shows the vertical scratches due to scuffing. The scratching grooves increase the oil consumption and blow-by (Jeff Smith, 2019).

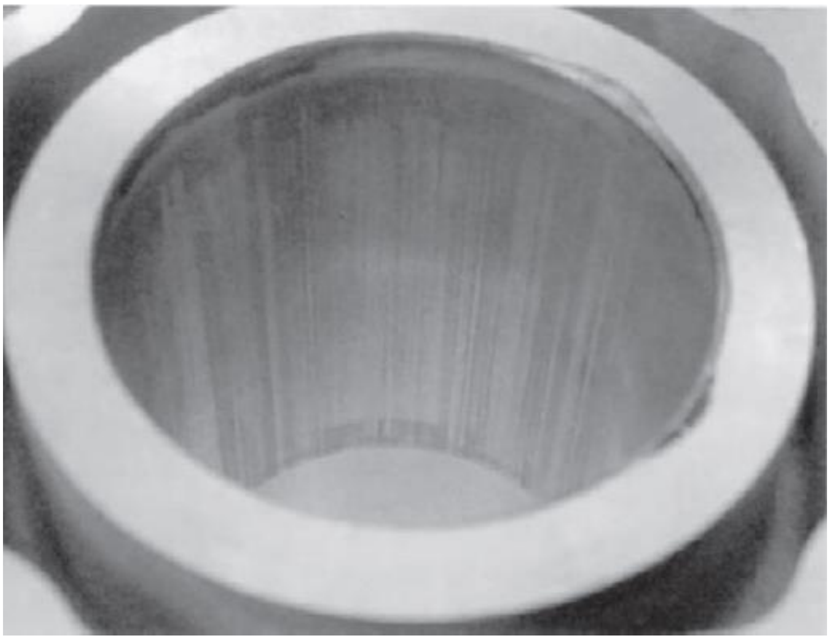


Figure 1.2: Vertical scratches due to scuffing inside the engine block (Hiroshi Yamagata, 2005)

A separate cast piece known as the cylinder head is covering the top of the cylinder. The cylinder head is bound to the top of the engine block by using bolt. In addition, the cylinder head is fitted some parts which is spark plug on the top, combustion chamber or known as a cylinder block and also fitted with valve for some engine. The main pupose of the cylinder head is to seal the cylinder's working ends and not to allow the gasses to enter and exit overhead valve engines (Vishal Sapkal, 2018). Heat generated during combustion is converted into mechanical power on the crankshaft and part of it loss through exhaust gasses and heat transfer to the environment. The cylinder head must withstand enermous pressures and very high temperature while retaining its shape and forming through the head gasket to seal the cylinder block. Figure 1.3 shows the example of the cylinder head.

Figure 1.3: The example of the cylinder head (David Fuller, 2015)

1.2 Problem Statement

Engine block will expose to high temperature during its operation. From this situation, the temperature will effect the strength of engine block and cylinder head. Usually, the effect of temperature will lower the yield stress of material of engine.

Besides, finite element model is widely used to predict stress of engine block. However, this finite element model fail to predict the stress of engine accurately. The best way by run the experiment to predict stress value on the engine block but it is costly and time consuming.

Furthermore, after the new engine was design, there is a constraint which is the engine is heavy and the geometry is quite large. Hence, the heat transfer from the surface to the surrounding is slow.

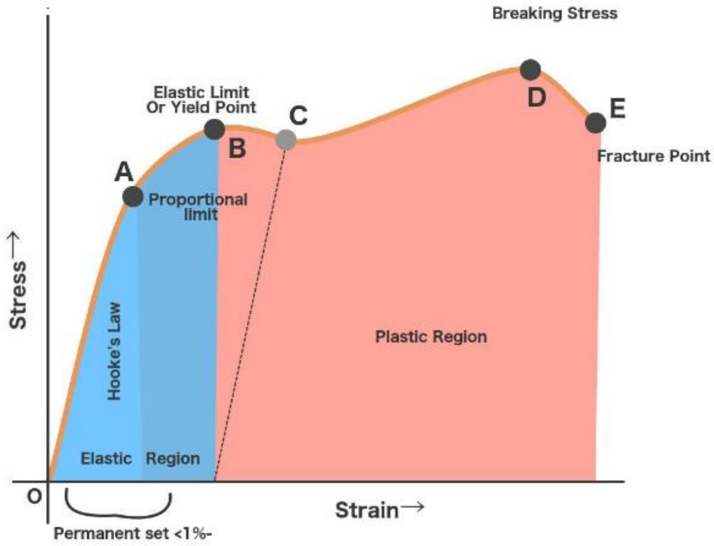


Figure 1.4: The general stress-strain graph for yield strength (Akash Peshin, 2016)

1.3 Objectives

The objectives of this project are as follows:

1. To determine stress of engine block for 2-stroke engine.

2. To compare the experiment and simulation result of the engine block.

1.4 Scope of Project

This study is to evaluate the stress of the two strokes engine. The experiment is use a pocket bike engine by changing the original engine block with the gray cast iron material of the engine block and cylinder head. The study also deals with analysis of product consists of two components, engine block and cylinder head. The CATIA software is used for design and ANSYS software is to make a simulation. Lastly, the material used for the engine block and cylinder head is gray cast iron while for the fin is used aluminium.

CHAPTER 2

LITERATURE REVIEW

2.1 Internal Combustion Engine

The fundamental chemical process of releasing energy from a fuel and air mixture is combustion, also known as burning. The ignition and the combustion of the fuel and air mixture happen in the engine by itself. The energy that created by the combustion will be converted to work. The combustion cause the piston move upward and downward which drive the crankshaft to rotate. Eventually, the system of powertrain drives the vehicle's wheel.

Nowadays, there are two types of internal combustion engine that has been used world widely which are the spark ignition gasoline engine also known as petrol engine and the compression ignition diesel engine. The basic cycle processes of the engine is intake, compression, ignition and exhaust (Jia *et al.*, 2016). There are some differences between the spark ignition gasoline engine and the compression ignition diesel engine on how they supply and burn the fuel.

For the spark ignition gasoline engine, there are two types of system to inject the fuel into the cylinder which are by using carburetor and fuel injected. During the process in carburetor, the fuel and air mixed before inducted to the cylinder but different with fuel injected where the fuel and air mixed in a cylinder. However, the concepts of these two types of mechanism still same because the ignition needs a fuel mixed with air during intake process to start the combustion during the piston compresses the fuel-air mixture.

For the diesel engine, there are two types of fuel system which are direct injection and indirect injection. In direct injection, the fuel was sprayed directly on top of the piston. The characteristic of this system is high fuel efficiency, noisy and easy cold starting ability. For indirect injection, the fuel was sprayed to a pre-chamber. The characteristic of this system is less fuel efficiency, less noise and need a pre-heating before starting. The concepts of these two system is the air fuel mixture ignites at high pressures and temperatures. The top dead center (TDC) is called when the piston reach at the highest point and the bottom dead center (BDC) is called when the piston reach at the lowest point in the cylinder. The ratio of the fuel to air is not the same throughout the cylinder for both diesel and spark ignition. In term of fuel consumption, about 27% efficiency of the engine, 30% is lost to the jacket cooling and 30% is exhausted to the environment (Humphrey, 1989). The ratio of the fuel to air is not the same throughout the cylinder for both diesel and spark ignition engine.

In any internal combustion engine, a cooling system is required. The function is to remove the excess heat from the engine and to make sure the engine operates at the most ideal temperature (Baba, 2007). Approximately, one-third of the fuel energy is converted into power. The exhaust pipe is another third unused and the other third becomes heat energy. Liquid cooling and air cooling are the types of cooling system. Basically, air cooling system is more often used in aircraft, motorcycles and lawnmowers and liquid cooling system is used in auto engine (University, 2018). The heat transferred from the combustion chamber to the cylinder head and dissipated into the air must be recovered (Baba, 2007).

A huge number of dissimilar design of internal combustion engine has been developed and formed for a different type of purpose and have their own strength and weakness. Since the internal combustion engine lead as a power supply for cars, boats and aircraft, it shows that the real strength of internal combustion engine is in vehicle application.

2.2 Type of Engine Cycle

There are many engine cycle types but usually two stroke and four stroke has been used. Every type of engine cycle has their own process, characteristic, advantages and disadvantages.

2.2.1 Four stroke

A four stroke cycle engine is an ICE that uses for different piston stroke (intake, compression, ignition and exhaust) to complete a single operating cycle. During the operating cycle, the crankshaft will rotate for two revolutions (720 degree). The most common type of small engine using the four stroke cycle engine.

The four stroke cycle engine comprises on oil tank, a crankshaft chamber and a lubrication system. Furthermore, the four stroke engine consists of a cam and a transmission mechanism connected between the cam and the chamber of the crankshaft in a matching manner (Bortolin and Hollis, 2017). In the first stroke, the piston travels downward while the intake valve open consists of fuel-air mixture being sucked because of the pressure difference. For the second stroke, the piston moving upward compressing the fuel-air mixture while the intake and exhaust valve were closed. When the piston reaches the TDC, the spark plug fires and burn the fuel-air mixture thus sending the piston to BDC. This process is called combustion stroke, also known as ignition. The last stroke is the exhaust stroke. As the piston moving upward, the exhaust valve is open to release the burnt fuel-air mixture to the exhaust pipe. When the piston at the TDC, the intake valve is open and the cycle begin all over again.

Due to high emission, high oil consumption and high noise, two stroke engine cannot meet increasingly stringent standards, as environmental protection and energy saving requirement are becoming increasingly strict at home and abroad (Daobing Huang, 2016) while in general, four stroke engine produce more torque, fuel efficiency, durability and less pollution. At low revolution per minute (RPM), four stroke cycle engine always make additional torque than two stroke engine and is very suitable for heavyweight vehicle such as car and lorry. Besides, the four stroke cycle engine have a higher fuel efficiency than two stroke engines because once every four strokes fuel is consumed. Since the power is generated once every four stroke and no oil or lubricant is added to the fuel, the four stroke cycle engine causes less pollution. However, the engine is expensive and more complex compare to two stroke engine.

2.2.2 Two stroke

The two stroke engine is the simplest engine because it requires two stroke to complete one revolution for the engine process. A two stroke ICE with a compressed air inlet port and an exhaust port that controls the flow through appropriate valve (Coney et al., 2005).

As the two stroke's piston rises on compression, the negative pressure is created in the crankshaft. This negative pressure causes the fuel-air mixture to be inserted into the crankcase (Uenoyama et al., 2001). Some of type of intake port such as cylinder wall port, reed valve or rotary disk valve is open, it is allowing fuel-air mixture to flow through a carburettor into the crankshaft. When the piston reaches the TDC, at high pressure, a spark fires the compressed mixture. In the other word, the fresh intake charge is drawn into the combustion chamber and the previously burned charge is exhausted at the same time (Tomio Iwai, 1989).

However, there is a risk that the chamber will not be completely cleaned from the past combustion product due to the incoming fresh fuel-air mixture that will pass through the exhaust port and will be lost without being burnt. The advantages of two stroke engine is lighter, simpler, less expansive to manufacture. Compared to four stroke engine, the combination of light weight and double the power gives two stroke engine a great power-to-weight ratio.

2.3 Working Principal of Two Stroke Engine

As the one cycle is fully completed in one crank revolution, the operation sequence of the parts can be represented in a circle (360 degree). The timing diagram and P-V diagram appears in Figure 2.1 and Figure 2.2.

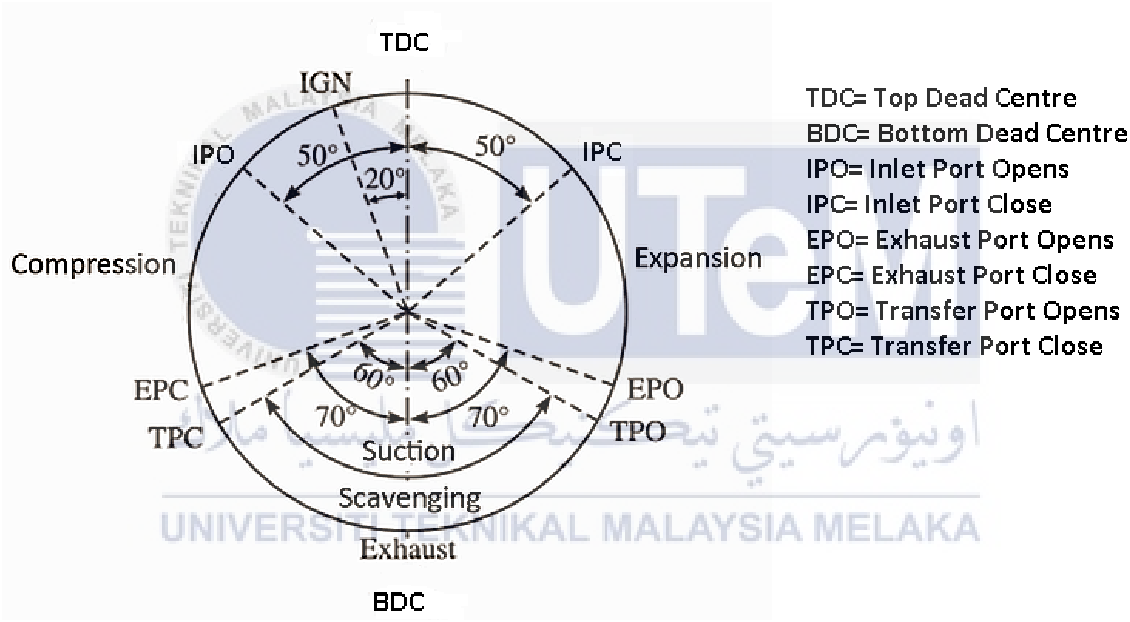


Figure 2.1: Timing diagram of two stroke Otto cycle (Saifadmin, 2018)

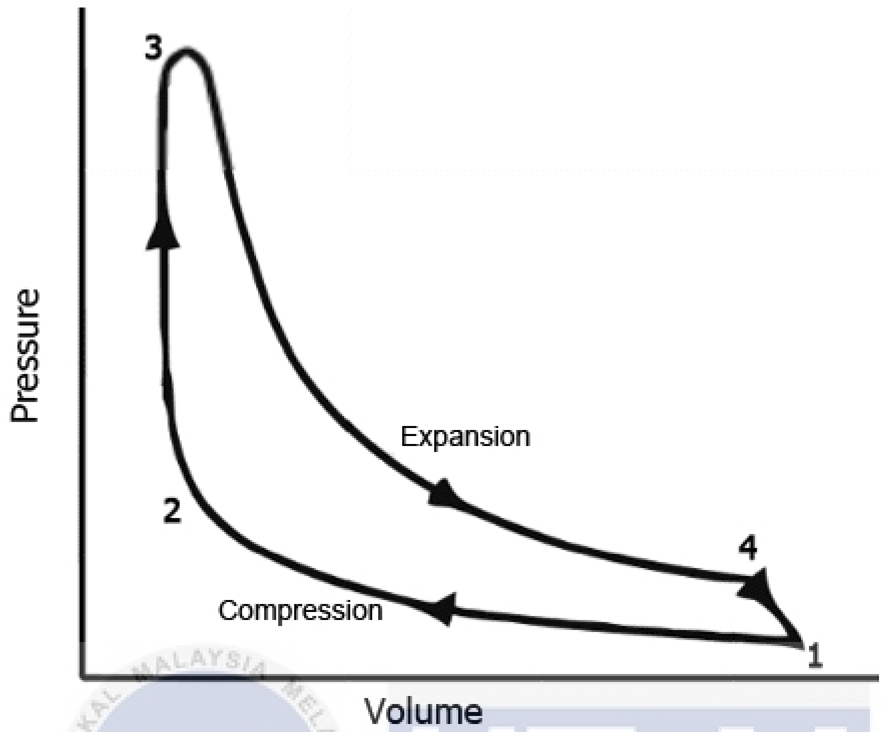


Figure 2.2: Actual P-V diagram for two stroke Otto cycle (Saifadmin, 2018)

2.3.1 Intake

The fuel-air mixture is first drawn into the crankcase by the vacuum produced during the upward piston stroke. The illustrated engine has poppet intake valve as shown in Figure 2.9, but many engines use a rotary valve in the crankshaft.

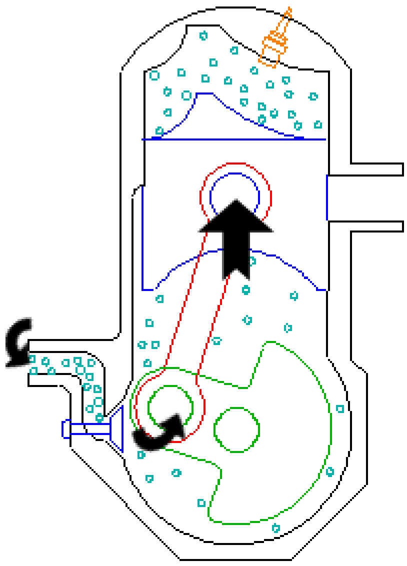


Figure 2.3: Illustration of intake process (Matt Keveny, 2011)

2.3.2 Compression

The piston compresses the fuel-air mixture during upward movement, driven by flywheel momentum. At the same time, another intake stroke occurs under the piston.

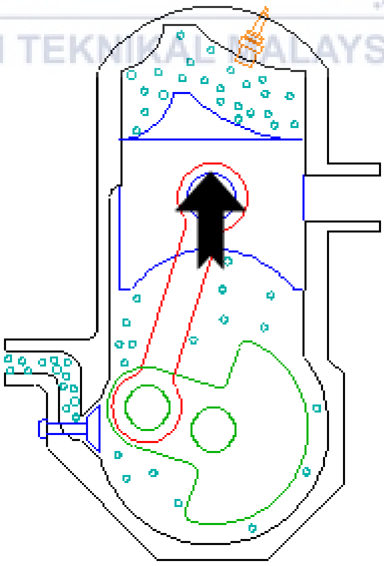


Figure 2.4: Illustration of compression process (Matt Keveny, 2011)

2.3.3 Power

At the TDC, the spark plug ignites the fuel-air mixture. The fuel that burns expands and drives the piston down to complete the cycle. At the same time, another crankcase compression stroke takes place under the piston.

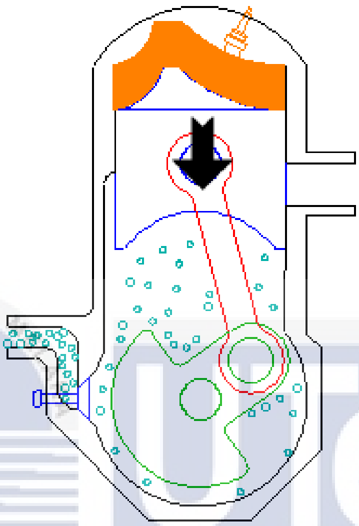


Figure 2.5: Illustration of power process (Matt Keveny, 2011)

2.3.4 Exhaust/Transfer

The piston exposes the intake port towards the end of the stroke, allowing the compressed fuel-air mixture to escape to main cylinder around the piston. This removes the exhaust gas from the exhaust port which is usually on the opposite side of the cylinder but some of the fresh fuel-air mixture is unfortunately also removed.

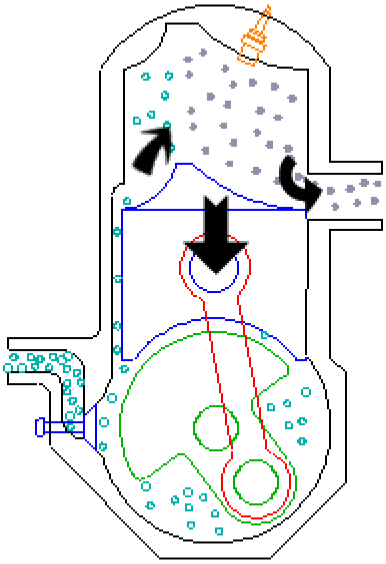


Figure 2.6: Illustration of exhaust process (Matt Keveny, 2011)

2.4 Effect of temperature on cylinder head and cylinder block

This country is one of the tropical country with a very wide range of temperature deviations. Because of that, it is very difficult to say which temperature is the best suited for the engine operating conditions and gives the best possible performance in term of thermal efficiency and braking power.

The high temperature occur during the combustion process in order to burn the air-fuel mixture. But, at the same time the engine need a controllable level of temperature in order to operate engine safely. Once the engine temperature has reached intolerable values, it can damage the engine block and components (Suresh konda, 2017). Spark plug, piston face, exhaust valve and port are the component with the highest temperature. The problem with these components are that there are not only the hottest component, they are difficult to cool as well because the location of the components in the engine does not allow them for proper heat transfer. If an optimum temperature is not reached, the expansion is either excessive or insufficient and may cause complications in the engine's operating efficiency (Ajay K. Singh, 2013).

Besides, the advantages of the increasing the temperature is reducing the specific fuel consumption while low temperature will have a good impact on reducing the chance of knocking and pre-ignition, and increasing volumetric efficiency (Sunil Choudhary, 2014). Other important reasons including material limits, lubricant performance limits and emission, require the optimum engine temperature.

Hence, a heat removal process that will keep the engine in a safe operating condition is essential. The two type of engine cooling system for heat transfer from the engine block and head that commonly used are liquid cooling and air cooling. In addition, when the engine is in operation, the lubricant is required to perform many different task. The primary function of lubricating all components by reducing friction or preventing metal contact with metal (A.F.A. Rasid, 2012). These oils are designed to operate optimally at the engine's normal operating temperature range. As the general rule of thumb, the operating temperature of an engine should be about 10°C to 15°C above the temperature of the cooling water (Muwafaq Mahdi Abd, 2012).

2.5 Internal properties of ICE

Internal properties act as a parameter which can be obtain from the operation of the internal combustion engine. Sometimes, internal properties of engine will be effected the engine performance.

2.5.1 Temperature distribution

Temperature is a measure of the average molecular movement energy in a substance, whereas heat is the total molecular movement in a substance. Heat transfer is a parasitic process that help to reduce fuel conversion efficiency. The heat comes from the internal combustion working. Due to (C. P. Chiu, 1987), the cylinder temperature increase as the engine speed increase. However, the fin or air cooling system emit heat from the engine through forced convection into the atmosphere. The heat transfer rate depends on the wind speed, geometry of the engine surface, exterior surface area and ambient temperature (Pulkit Agarwal, 2011).

There is some impact due to the engine heat transfer. Firstly, the efficiency and power. The inlet heat transfer reduces volumetric efficiency. The heat losses to the wall in the cylinder are loss of availability. The heat transfer of the in-cylinder and exhaust system has an effect on catalyst light. Next, the heat transfer also controls the temperature of the liner, piston/ring and oil. It also affects distortion of piston and bore. All of these effects affect friction. Then, the heat transfer effect the durability of critical engine components. Heat transfer also affects the build-up of the cylindrical deposit that affects the knock.

2.5.2 Thermal expansion

In an internal combustion engine, combustion occurs at high temperature and pressure, which can affect chances of piston seizure, overheating, piston ring chances, compression ring and oil ring. Excess temperature may also damage the material of the cylinder block. Heat release into the atmosphere through forced convection in air-cooled motorcycle engines (Shubham Shrivastava, 2016). The heat transfer rate depends on wind speed, engine surface geometry, external surface area and ambient temperature. There is an optimal cooling rate of an engine for its efficient operation. If the cooling rate decreases, overheating will result in engine seizure. Simultaneously, an increase in cooling rate affects engine start-up and reduces efficiency (Pulkit Agarwal, 2011).

2.6 Cooling System of Two Stroke Engine

The cooling system is one of the important system that every engine need in order to maintain the range of the engine temperature during the operation. It helps the engine to achieve high efficiency within the temperature range. Depending on it, a good cooling system has a high heat transfer rate as the engine operates at high temperatures. The effective cooling rate will provide the performance of the engine to make it more efficient. According to (Alessandro Franco, 1998), the heat transfer between gas and cylinder is the most important thing in the internal combustion engine for its functioning and reliability. There are three cooling system mediums that are air-cooled, water-cooled and oil-cooled. These three mediums give the difference resulting from the cooling rate based on engine type suitability.

2.6.1 Water-Cooled System

The examples of the cooling system invented by other researchers are variable timing of exhaust port and water jacket for improved efficiency(Oku and Yasuharu, 1980). Another example of a cooling system is called the OP2S cooling system to increase durability and the cooling cylinder. The cylinder liner's surface temperature is limited to 270 ° C. The hot-side boundary conditions were defined at the first design stage and the heat flux distribution within the cylinder wall was predicted based on the correlation of Nusselt numbers. In addition, air temperature was determined during compression and combustion to simulate blowdown and scavenging. Next, the different "coolant jacket" design was studied to find the approximate uniform distribution of temperature along the cylinder and the cylinder was modified to convert the inlet slot into an impingement band. As a result, the axial temperature as shown in Figure 2.7 and Figure 2.8 is also significantly improved for overcooling.

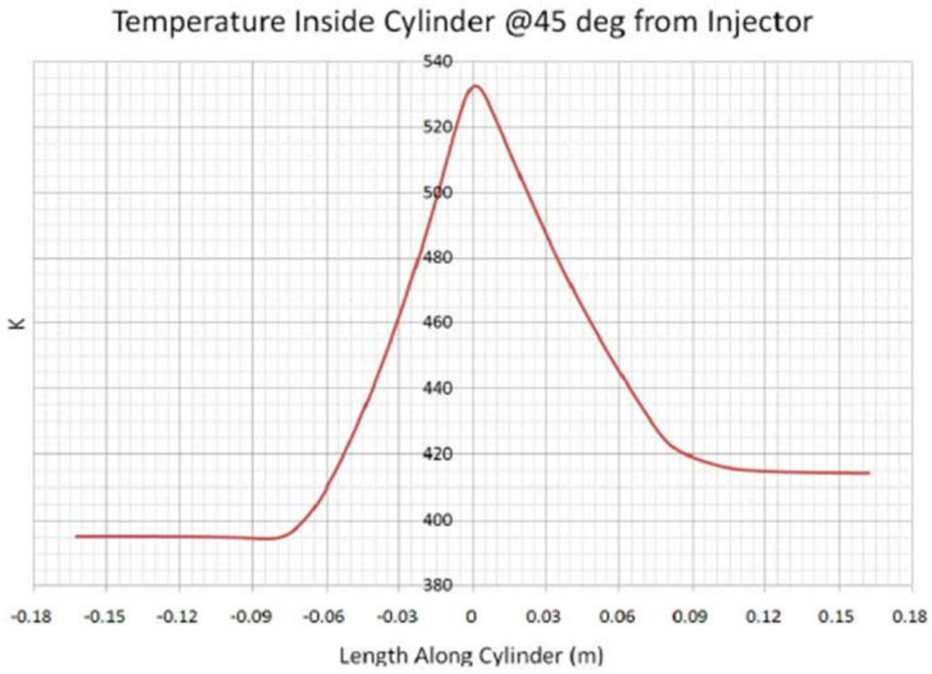


Figure 2.7: Axial temperature result of "Coolant Jacket" (Patrick Lee, 2012)

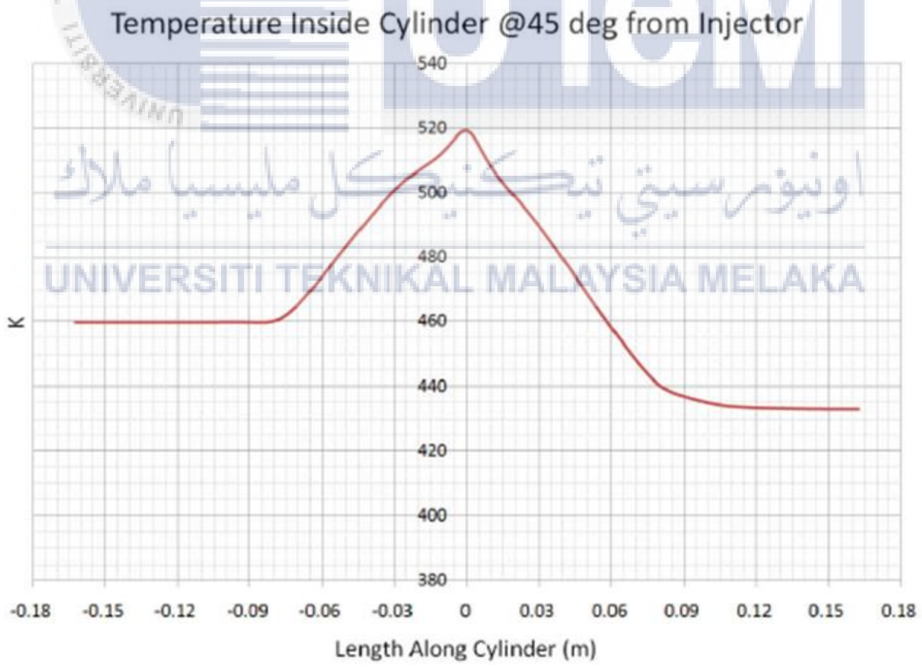


Figure 2.8: Axial temperature result of Impingement Band (Patrick Lee, 2012)

2.6.2 Air-Cooled System

Another type of cooling system is air-cooled, providing a lightweight and simple system (Sachin Kumar Gupta, 2015). The example of an air-cooled system is fin cooling. The fin is fitted around the engine block by temporary joint or permenant joint. The purpose is to increase the rate of heat transfer (L.Natrayan, 2016). However, this method only applies to moving vehicles because it depends on the speed of the vehicle and the ambient temperature (Patel and Vora, 2014). Nevertheless, according to (Kohei Nakashima, 2018), the cooling effect of fins can be optimized by increasing natural convection. To achieve this, special cooling fins with slits arranged in a fixed equiangular spiral are produced to decrease the temperature between the fins.

Based on the experiment that run by (Gibson, 2015), the hottest part of the engine is in the exhaust part. On the other hand, the smaller the cylinder diameter, the smaller the temperature difference between the engine's front and back. In addition, when the fins are attached to the engine either circumferential fins or longitudinal fins, the engine temperature decreases. Next, the fins that help to reduce the temperature are the fins with slightly concave surfaces and sharp tips. However, the loss of heat also depends on the material's conductivity and wind speed.

According to the exxperiment that have been done by (Biermann and Benjamin, 1934), two problems associated with fin cooling involve heat convection from the surface of the fins by air flow and heat conduction between the fin surfaces. Figure 2.9 below shows the diagram of the fin in this experiment. The heat transfer coefficient depends on the air speed and the pitch of the fins are the conclusion that can be made from the research. Then, the smaller the pitch of the fins, the more efficient it is possible to design the fins weight.

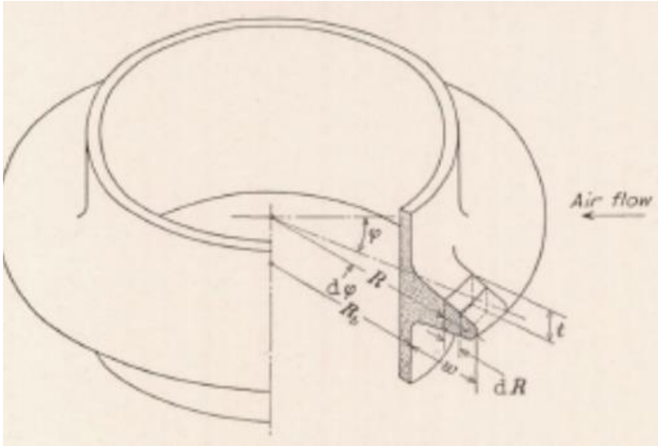


Figure 2.9: Fin diagram (Biermann and Benjamin, 1934)

In addition, the engine temperature must be maintained to ensure that the engine works properly, especially for the engine block and cylinder head components (David Thornhill, 1999). Figure 2.10 shows the fin geometry that has been used in the experiment by (David Thornhill, 1999). Adding fins helps to reduce temperature, but the coefficient of convective thermal transfer is found to differ predominantly with air velocity and fin separation as shown in Figure 2.11.

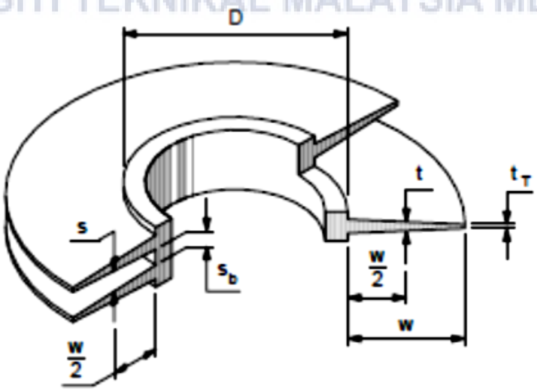


Figure 2.10: Fin geometry (David Thornhill, 1999)

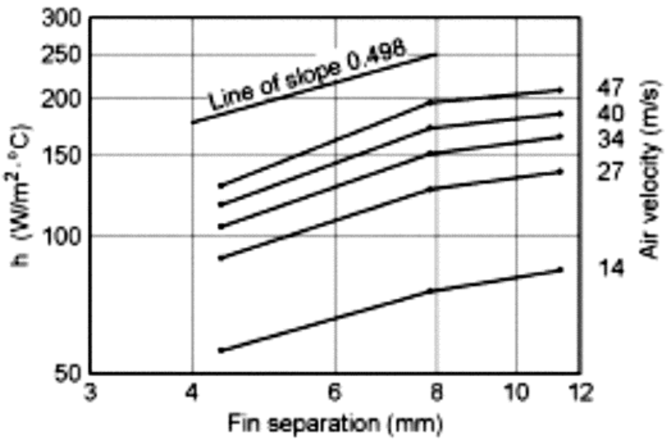


Figure 2.11: Relationship Between Air Velocity, Fin Separation and Convective Heat Transfer Coefficient (David Thornhill, 1999)

The fins help to remove heat from the combustion chamber wall and provide extended surfaces where heat is convected to the surrounding air. The convective thermal coefficient also depends on the length of the fins, other than fins separation and wind speed.

2.7 Gray Cast Iron Characteristic

Gray cast iron, a type of cast iron most commonly used in the manufacture of industrial components, is superior to that of other cast iron types and requires lower lubrication levels from the used metalworking fluid. The graphite in gray cast iron has a flake-like structure that is largely responsible for this metal's high machinability. The flake-like graphite structure creates discontinuities in the metal matrix and reduced cutting forces afterwards. During machining, graphite in gray cast iron also provides lubrication. Including the effects of the graphite structure on the machinability of the gray cast iron, the metal also contains compositional elements that contribute to improved machinability (R. Evans, 2012).

Gray cast iron is typically alloyed with higher sulphur and manganese levels compared to other cast iron forms. It was found that during machining, sulphur and manganese can combine to form manganese sulphide inclusions that serve as effective solid lubricants and contribute to the metal's machinability and extend the lifetime of the tools used. Gray cast iron is highly machinable and can often be efficiently machined using lower lubricating fluids such as clear synthetic solutions or translucent microemulsions. Figure 2.12 shows the cutting forces measured with different types of metalworking fluid used to machine a gray cast iron class 40.

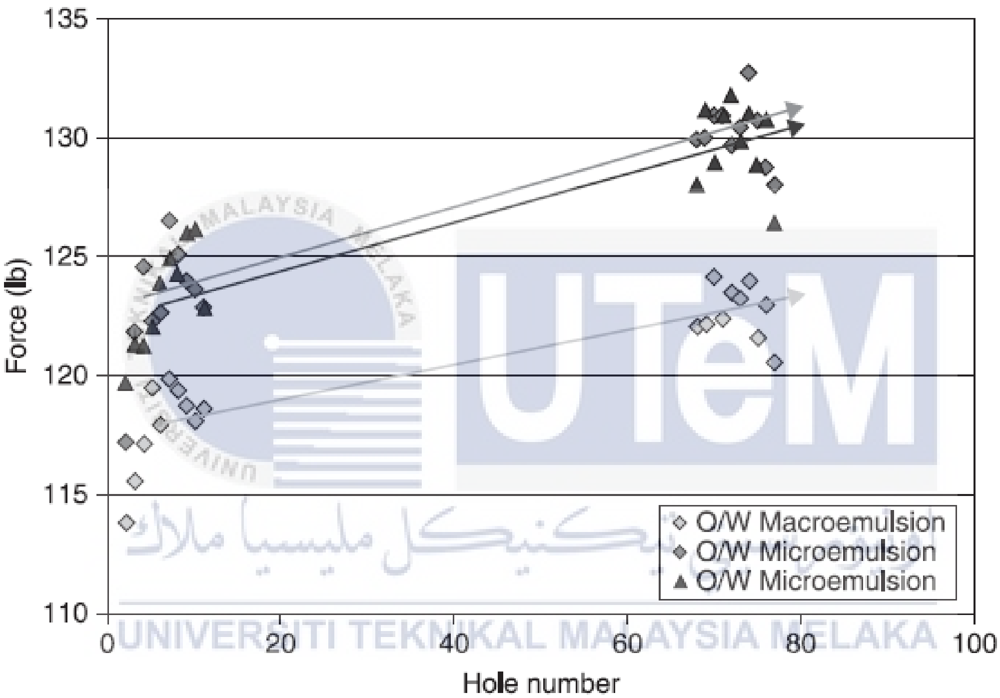


Figure 2.12: Cutting force with various metalworking fluid type (R. Evans, 2012)

Typically, gray cast iron alloys contain 2.5-4% carbon and 1-3% silicon, 0.2-1.0% manganese, 0.02-0.25% sulfur, and 0.02-1.0% phosphorus. It has excellent damping capacity, good wear and temperature resistance, is easy to machine and cheap to manufacture. However, gray cast irons are relatively weak and are prone to fracture and deformation (Pankaj Agarwal, 2017). Figure 2.13 shows the high-performance M3 coupe used by the BMW S54 inline-6. One possible reason the S54 block was made of gray cast iron was the need for a stronger material that could tolerate higher levels of performance.

Figure 2.13: BMW’s S54 inline-6 engine, which uses a gray cast iron engine block (Hieu Nguyen, 2005)

2.8 Finite Element Analysis On Engine Block

Finite Element Analysis (FEA) is a technique used to calculate the strength and behavior of engineering structures. It can be used for calculating deflection, stress, vibration, buckling behavior, and many other phenomena. The main objective of stress analysis is to keep the stress of working within its limits to evaluate the factor for the criteria of economic design and to improve the quality of the product (Shahanwaz Adam Havale, 2017). Material characteristics can be predicted successfully through stress analysis. According to the (Vikky Kumhar, 2018), in an internal combustion engine, the expansion of the high temperature and pressure gasses produced by combustion applies a direct force to the reciprocating piston, thus producing the crankshaft's rotating motion. This force moves the component, generating useful mechanical energy, over a distance. The finite element analysis was considered for the analysis and the results were obtained.

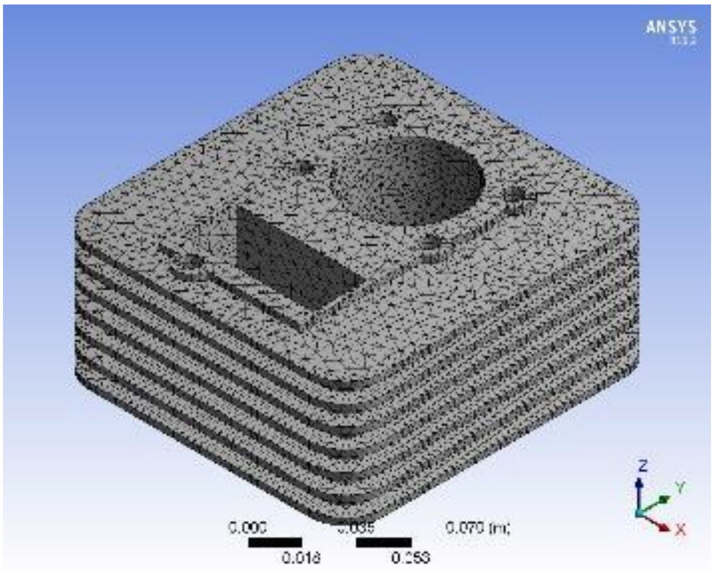


Figure 2.14: Meshed view for engine block model (Vikky Kumhar, 2018)

After a modelling part, the drawing was converted into the ANSYS software to make a finite element analysis. Figure 2.14 shows the step of meshing that have been done by (Vikky Kumhar, 2018). More than 100000 and 50000 nodes and elements are formed during meshing. Next, the boundary condition such as temperature were applied on the engine block as shown in Figure 2.15. In last step, the result of temperature and heat flux distribution were obtained as shown in Figure 2.16 and Figure 2.17.

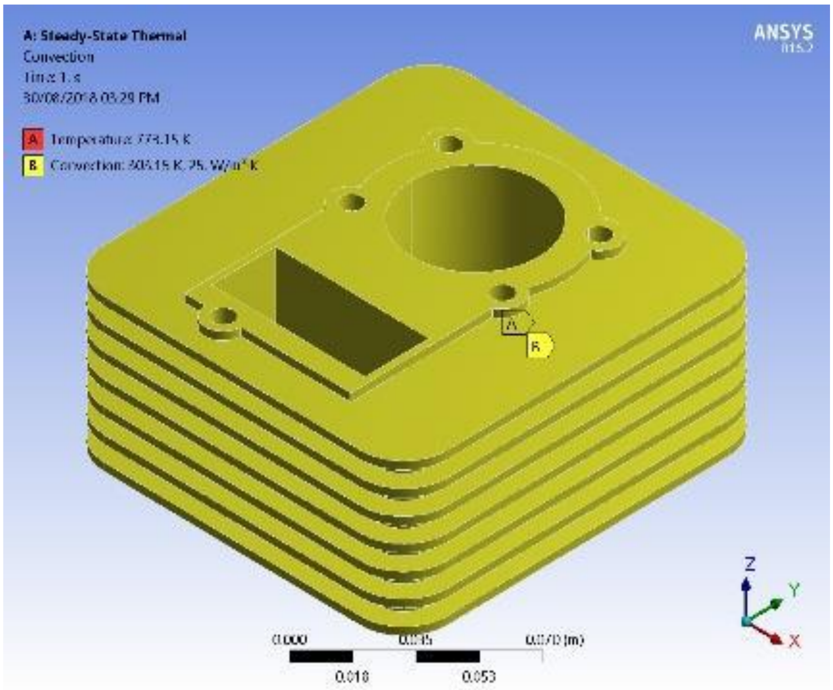


Figure 2.15: Boundary condition applied (Vikky Kumhar, 2018)

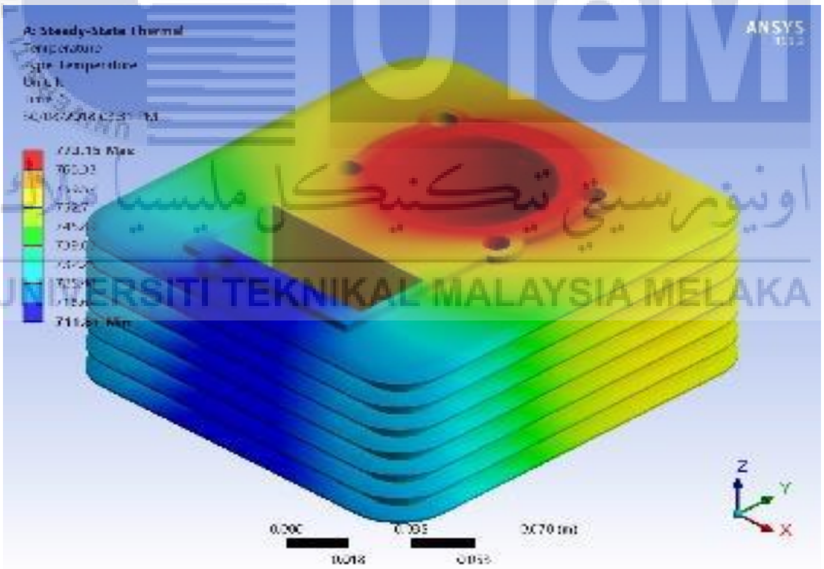


Figure 2.16: Temperature distribution result (Vikky Kumhar, 2018)

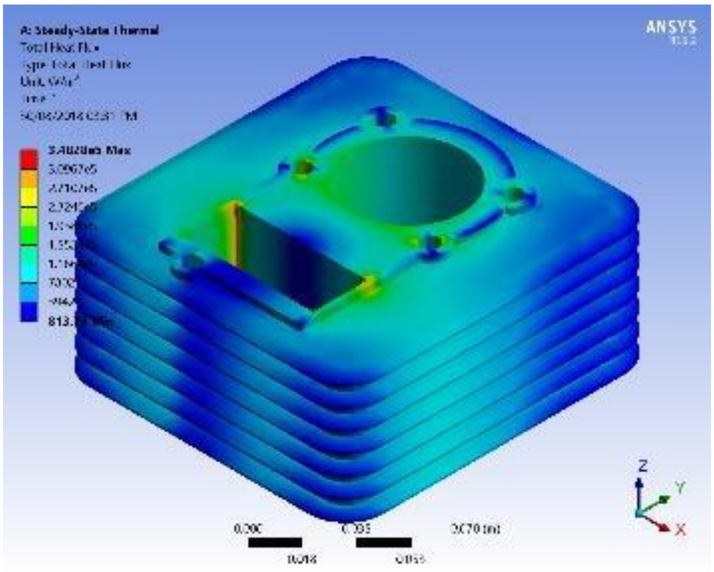


Figure 2.17: Total heat flux distribution result (Vikky Kumhar, 2018)

The cross section of the fin was observed to be the main heat transfer factor. In addition to the distribution of temperature, the mechanical load was also applied to the relevant areas. According to (Athirah Abdul Aziz, 2015), the presence of the temperature distribution affects the resulting stress, so the stress analysis was performed using the thermal analysis data as their input. A finite element analysis was performed to check the thermal and mechanical stresses under operating engine loads. Figure 2.18 shows the result of stress over a combustion chamber and Figure 2.19 shows the the location of the maximum stress on the cylinder head.

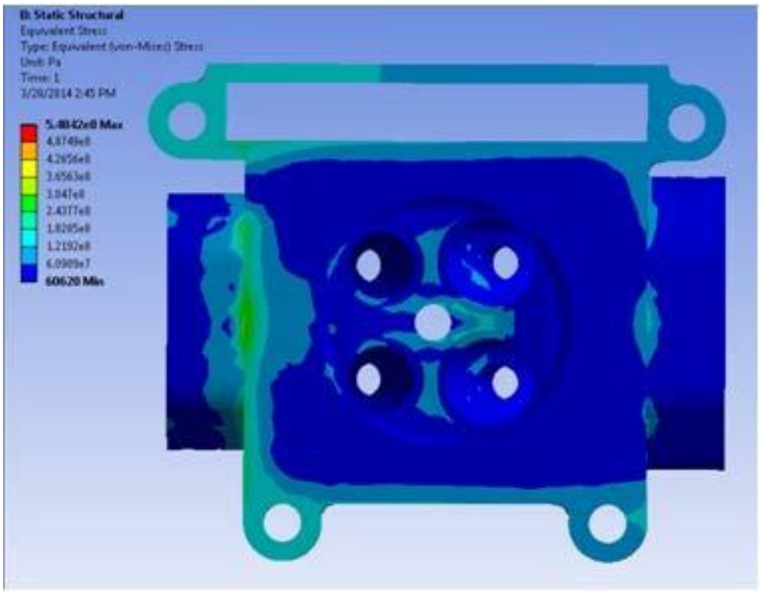


Figure 2.18: Equivalent stress over combustion chamber (Athirah Abdul Aziz, 2015)

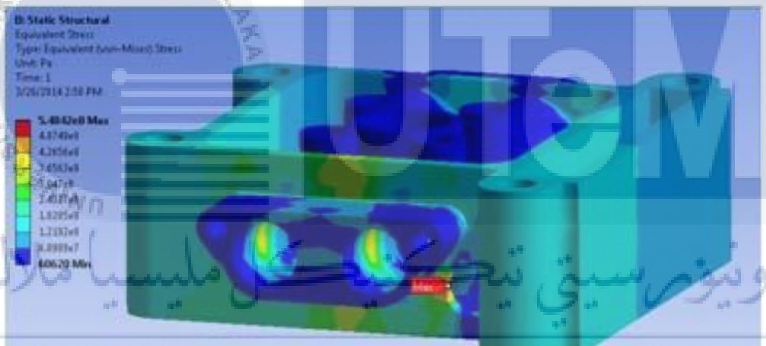


Figure 2.19: Location of maximum stress on the cylinder head (Athirah Abdul Aziz, 2015)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology is the study of measurement and analysis tools, research design and techniques. The methodology is divided into several stages to achieve the objectives of project. Figure 3.1 shows all the details of process.

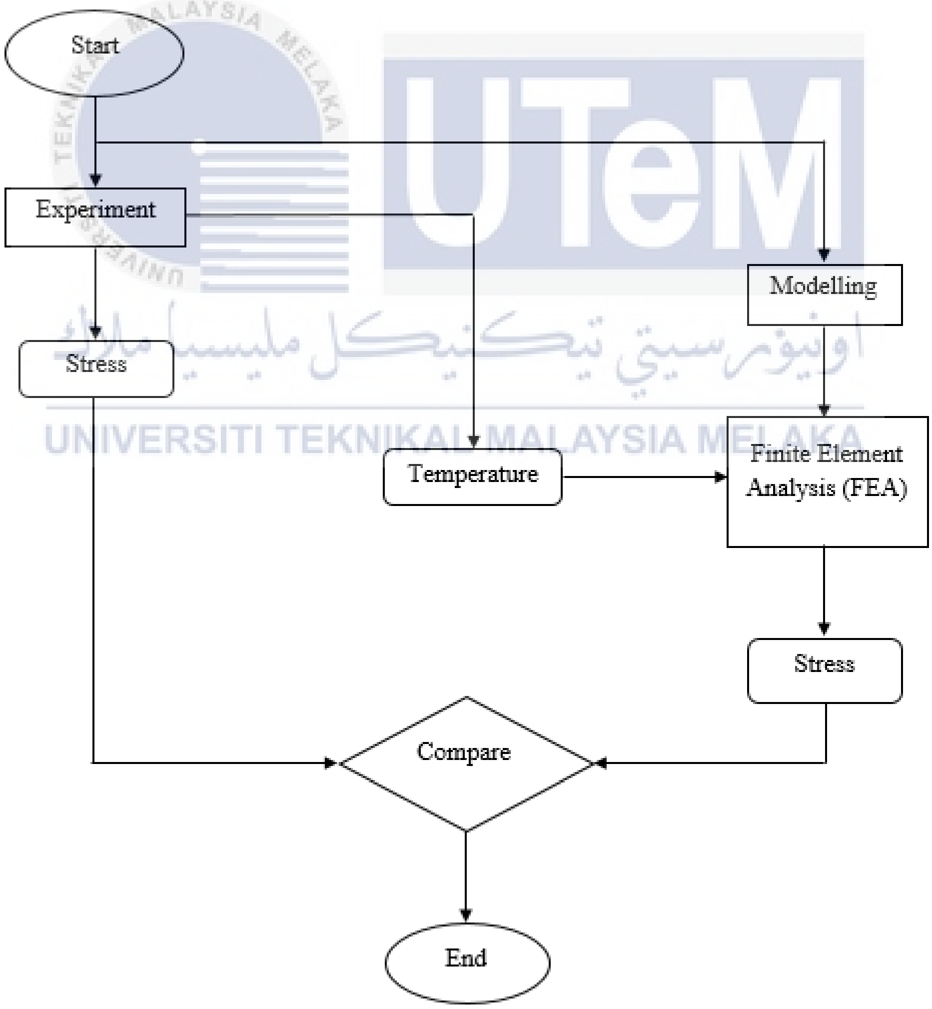


Figure 3.1: Flow chart of methodology.

3.2 Experiment

In this section, the equipment used in this project and the experiment procedure will be explain clearly. This section is important as a guide to do the experiment in order to achieve the objective of this study. The equiment used is suitable for this study.

3.2.1 Experimental Setup

There are several types of equipments used in this project. Each equipment used has its own functionality in the success of this project as shown in Table 3.1.

Table 3.1: Apparatus and functions

No.	Equipment	Function	Quantity
1	High temperature strain gauge	As a sensor to collect strain data at the certain position on the engine block.	2
2	Thermocouple	To measure temperature inside and outside the cylinder block.	3
3	Engine	As a main mechanism for this project where the internal combustion occur.	1
4	Data logger	To measure and record the temperature and strain data from the engine block.	2
5	502 super glue	As a joining mechanism to attach the high temperature strain gauge and thermocouple sensor on the engine block.	1

The high temperature strain gauge used can withstand up to 180°C in order to accommodating engine temperature during the operation. The K-type thermocouple that was used to measure the temperature inside the cylinder block can withstand up to 500°C. The length of the thermocouple sensor is 2meter and the type screw is M6 which is it can attach together with the cylinder head. A 502 super glue was used to attach the thermocouple and high temperature strain gauge around the cylinder block. 502 Super Glue is an ultra-fast, can withstand up to 97°C, low viscosity ethyl-based Super Glue that binds nearly immediately after contact. In addition, there are two data logger device was used to record the value of the temperature and strain during the experiment.

3.2.2 Experiment Procedure

Experiment procedure is a particular course of action intended to achieve a good result. This procedure will go step by step in order to achieve the value of temperature and stress on the engine block. The value of pressure defined through the formula (3.1) below by using the temperature from the experimental data. The value of the pressure is needed to insert into the simulation software that will come out with the value of stress in FEA.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \tag{3.1}$$

$$V_{1,2} = \pi r^2 h \tag{3.2}$$

where P is the pressure, V is the volume, T is the temperature, r is the radius of the cylinder, and h is the height of the cylinder.

Firstly, the two stroke engine was placed with a stand to make it more stable. Then, the original block cylinder of the engine was changed with the gray cast iron material block engine and cylinder head as a purpose of study. Before that, the aluminium fin with three different design was installed around the engine block as a cooling mechanism. The fuel with lubricants was filled in the fuel tanks after the engine block and cylinder head was installed. One of the thermocouple was installed on the top of the cylinder head which act as a sensor to measure the temperature inside the combustion chamber and the other two thermocouple was installed at two point around the cylinder block which act as the temperature sensor around the engine block. The equipment used to get the strain value is high temperature strain gauge was attached next to the thermocouple sensor around the engine block as shown in Figure 3.4. The thermocouple and high temperature strain gauge was installed around the cylinder block by using 502 super glue. Figure 3.2 below shows the engine arrangement and Figure 3.3 shows an arrangement of the apparatus of this project.

Figure 3.2: The engine arrangement

Figure 3.3: The apparatus arrangement

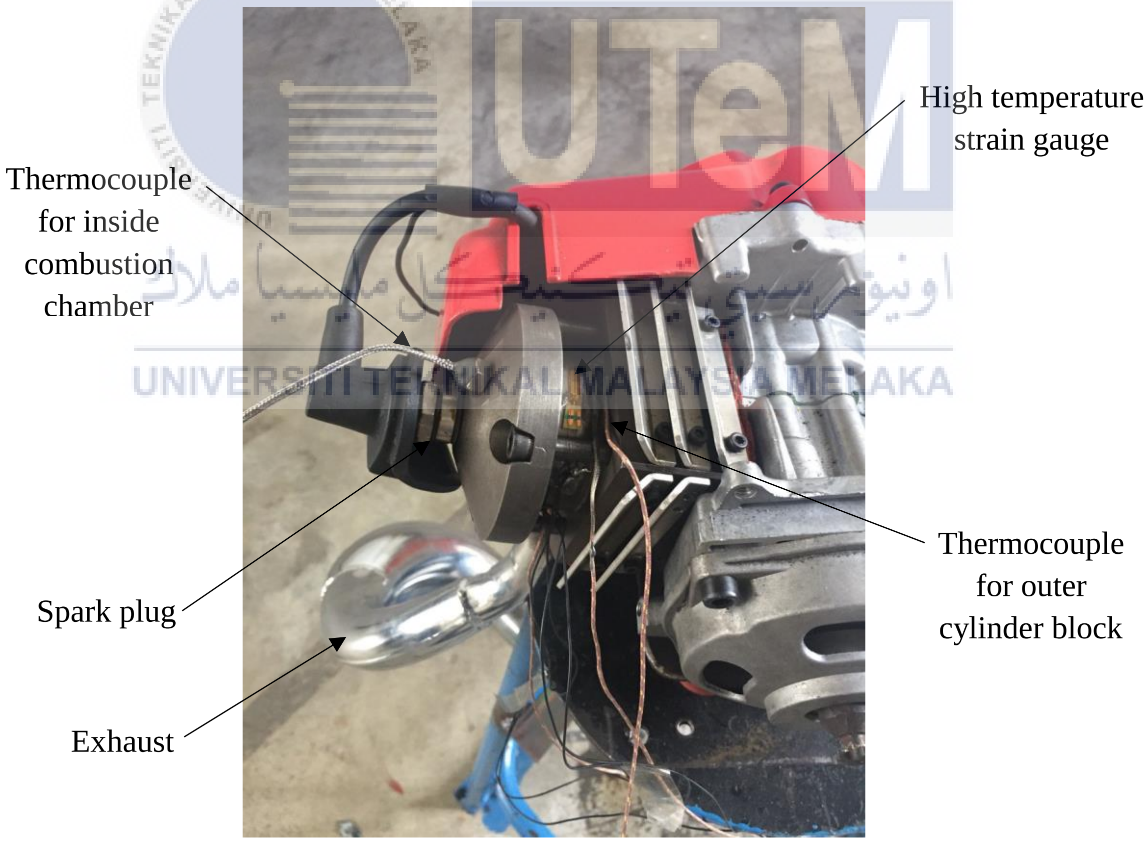


Figure 3.4: Close up engine

3.3 Design of Engine Component

The drawing design is carried out using the CATIA V5 software. The CATIA V5 is used to export the drawing design into the ANSYS software to run the FEA. Before the drawings were carried out, the measurement has been taken to make sure the drawing of the engine block has a same dimension with the real one. Figure 3.5 shows the original components of the engine block.

Figure 3.5: The real engine block with cylinder head.

The component that had been draw through CATIA V5 are engine block, cylinder head and fin. Figure 3.6 and Figure 3.7 shows the drawing of the cylinder block and cylinder head respectively.

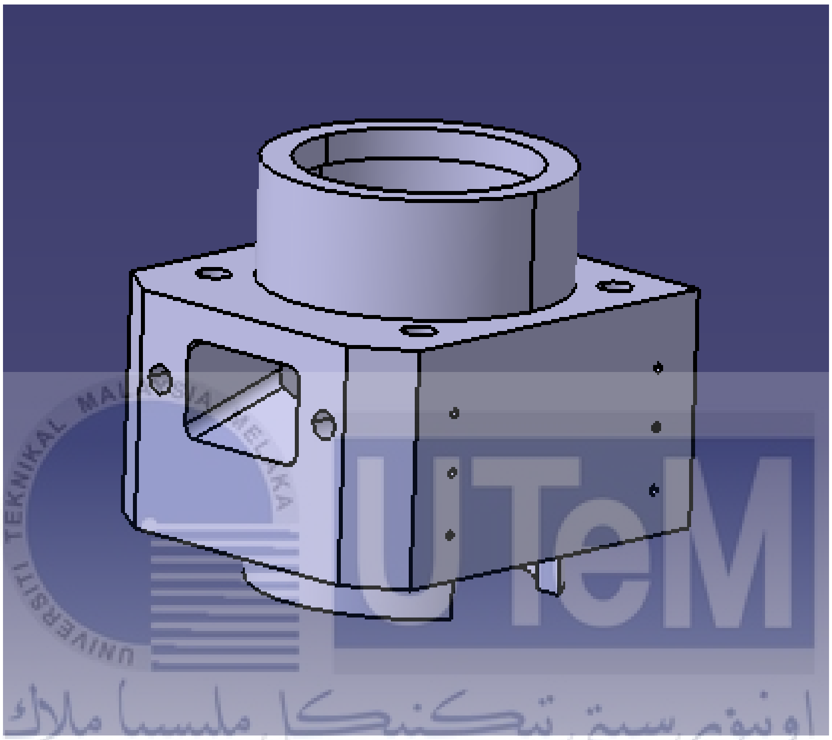


Figure 3.6: Drawing of engine block

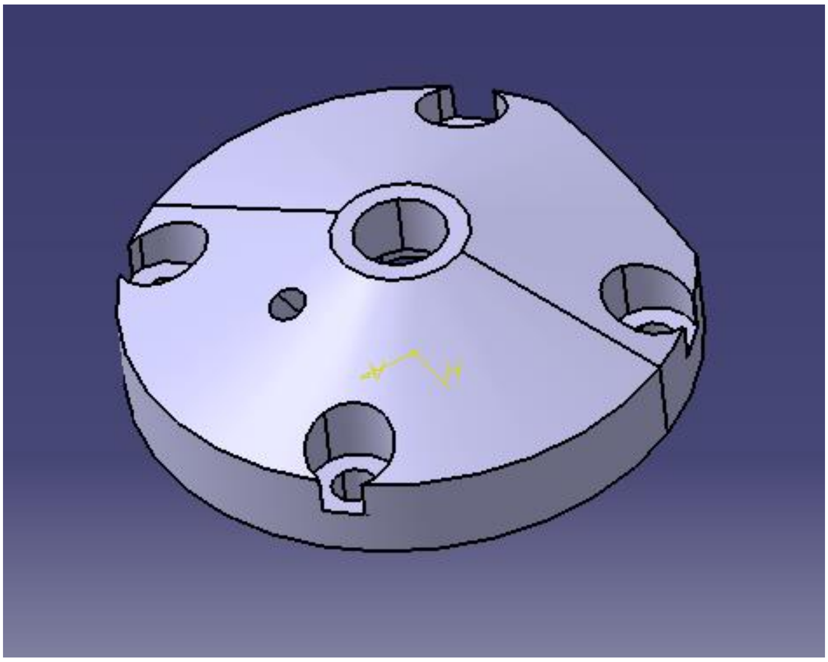


Figure 3.7: Drawing of cylinder head

There are some differences of fin design depends on the purpose. The fin is placed around the engine block as a cooling system. The figure below shows the differences design of fin that had been draw in CATIA software. Figure 3.8 shows the normal design of fin. The different shape of fin that shows in Figure 3.9 and Figure 3.10 is needed because of the position of the fin is in the line of exhaust piping. The shape was design to give the space for exhaust piping.

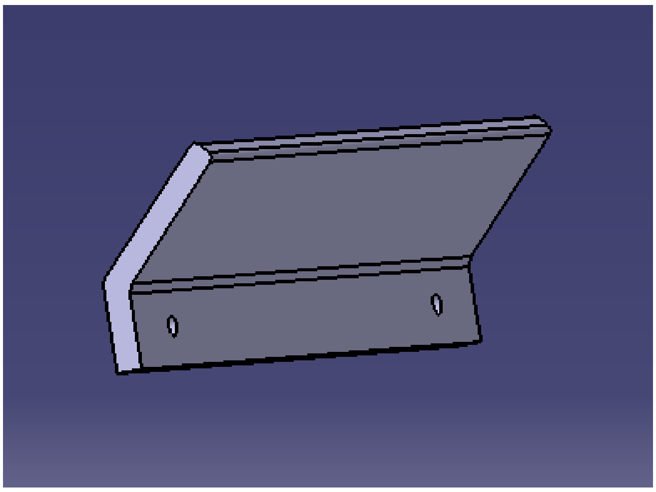


Figure 3.8: Drawing of a normal fin

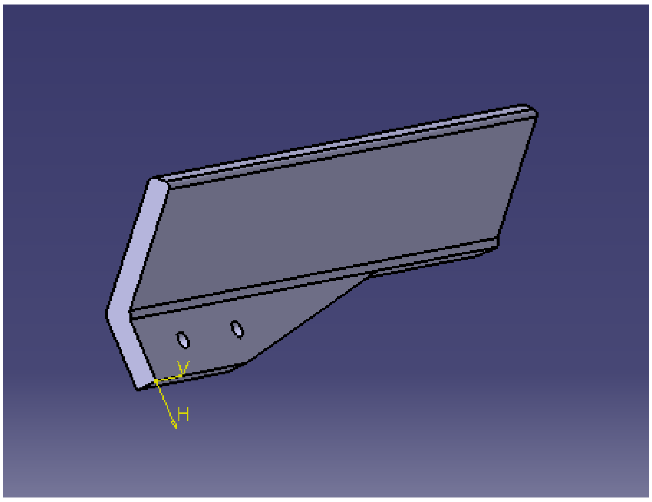


Figure 3.9: Drawing of fin

Figure 3.10: Drawing of another shape type of fin

After all the drawing part has done, the process continued with the assemble process. The assembled drawing shows in Figure 3.11. The purpose of the assembled drawing is to convert the drawing into the ANSYS software to make a simulation analysis. The file of the drawing in CATIA was set as a ‘igs’ or ‘stp’ file before import the assembled drawing into the ANSYS software.

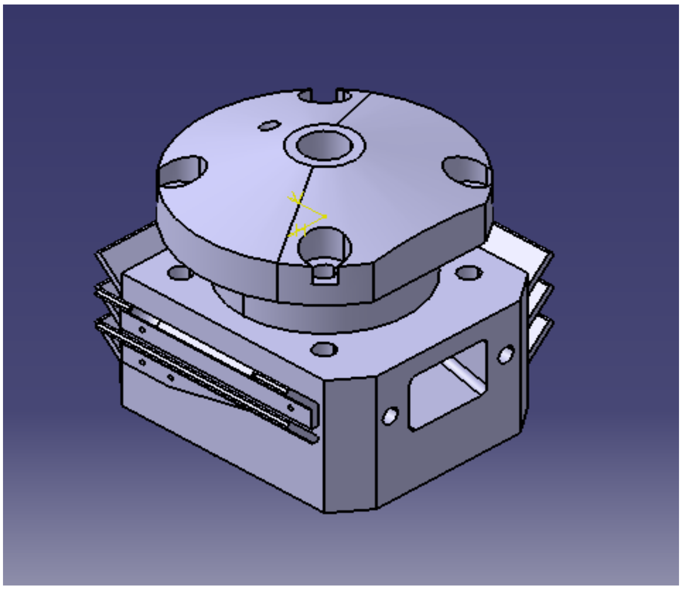


Figure 3.11: The assemble drawing

3.4 Simulation of Engine Block

In this section, the simulation process will be explain clearly. After the drawing process complete, the drawing design was transferred to an ANSYS software to proceed with FEA. Before that, the drawing file in CATIA was saved in 'iges' or 'stp' file format to transfer the file into ANSYS software.

In ANSYS software, there are many steps that need to be settle down before obtain the result. There are a lot of analysis system in ANSYS software. The analysis system that used in this project is static structural. Firstly, the material of all the component was chosen in engineering data part. In this project, the material used is gray cast iron for cylinder block and cylinder head and aluminium alloy for fin. Next, the geometry part. In this part, the assembled drawing file that has been saved in 'iges' or 'stp' format was chosen from the folder. After that, the model part is a part to upload the assembled drawing that has been chosen in a geometry part. Figure 3.12 shows that the assembled drawing file was uploaded in ANSYS software.

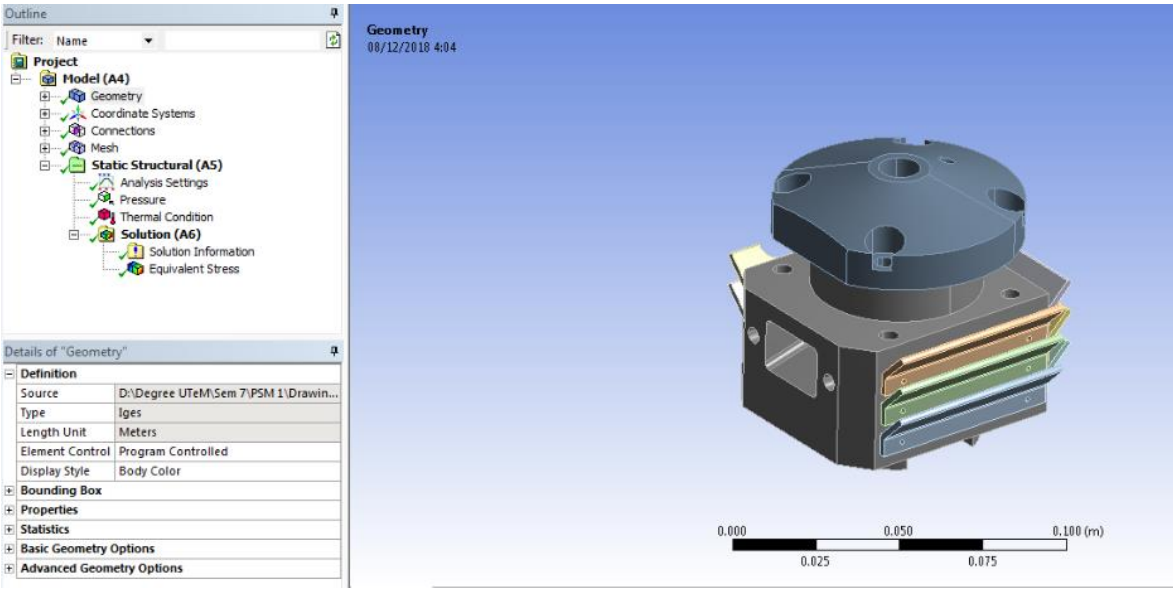


Figure 3.12: The file was uploaded into ANSYS software

As the assembled drawing was successful uploaded, each of geometry part was clearly declared as a gray cast iron for cylinder block and cylinder head and alluminium alloy for fin. Figure 3.13 shows each geometry part was declared with the material.

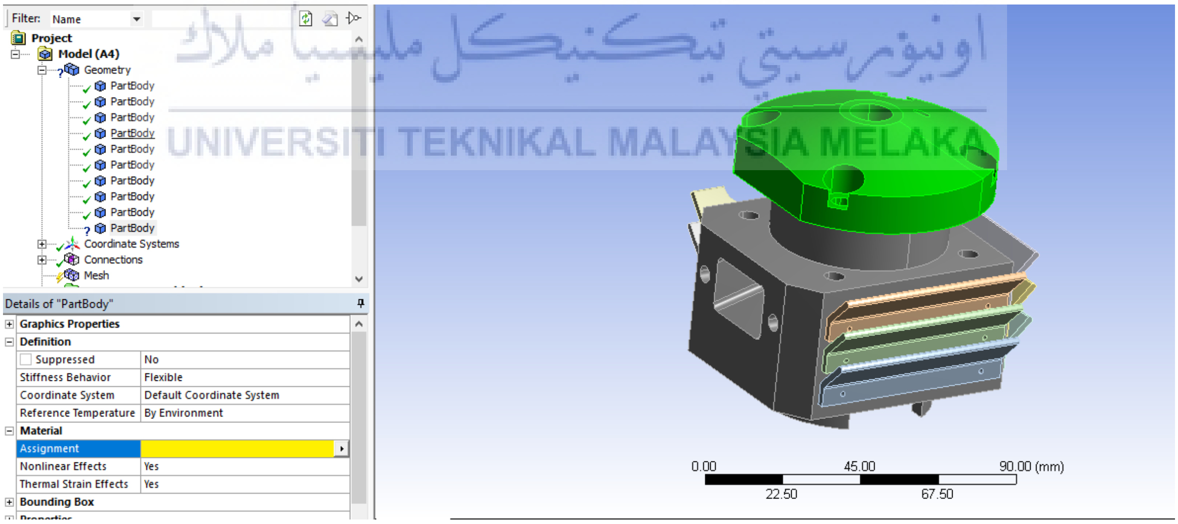


Figure 3.13: Declared each part with the suitable material

The next step is meshing. The generation of meshing is one of the most vital steps in the pre-process arrangement following domain geometry (Nawawi and Mohd, 2016). The coarse, medium and fine are the sizing of meshing that had been chosen. In this project, all of the three meshing sizing was used to find the exact value of the stress. The meshing function is to separate the structure element into small sizes. The result of FEA is more accurate by using the fine element meshing. Figure 3.14, Figure 3.15 and Figure 3.16 shows the coarse meshing, medium meshing and fine meshing respectively.

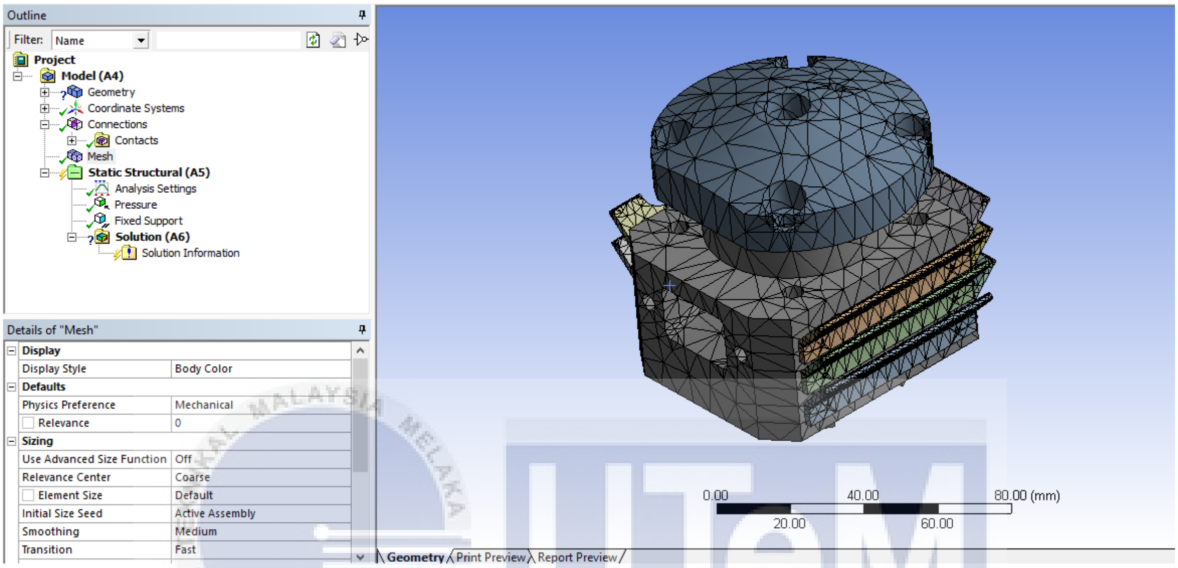


Figure 3.14: Size of coarse meshing

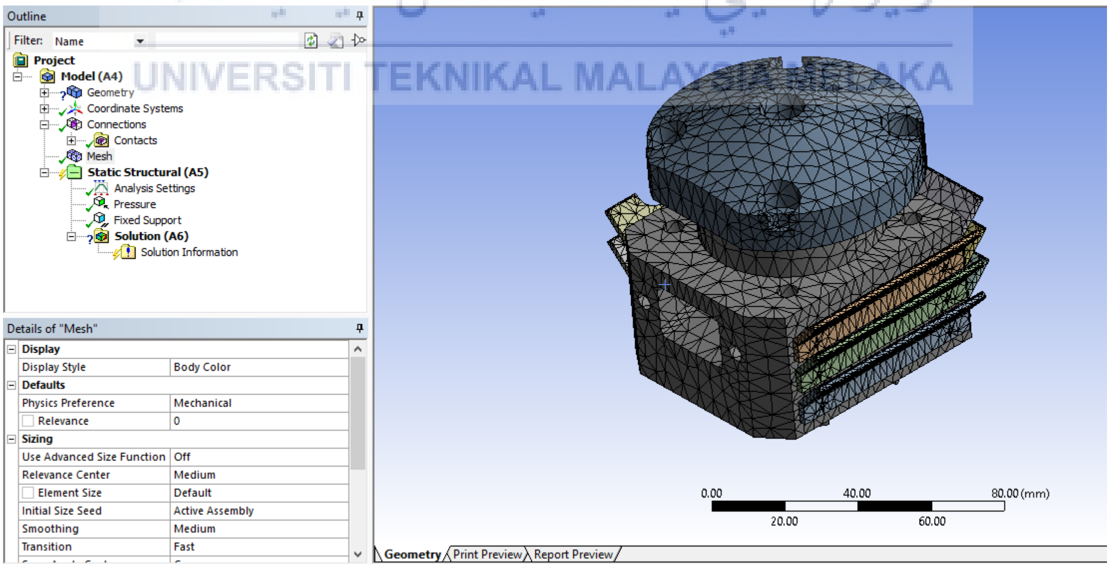


Figure 3.15: Size of medium meshing

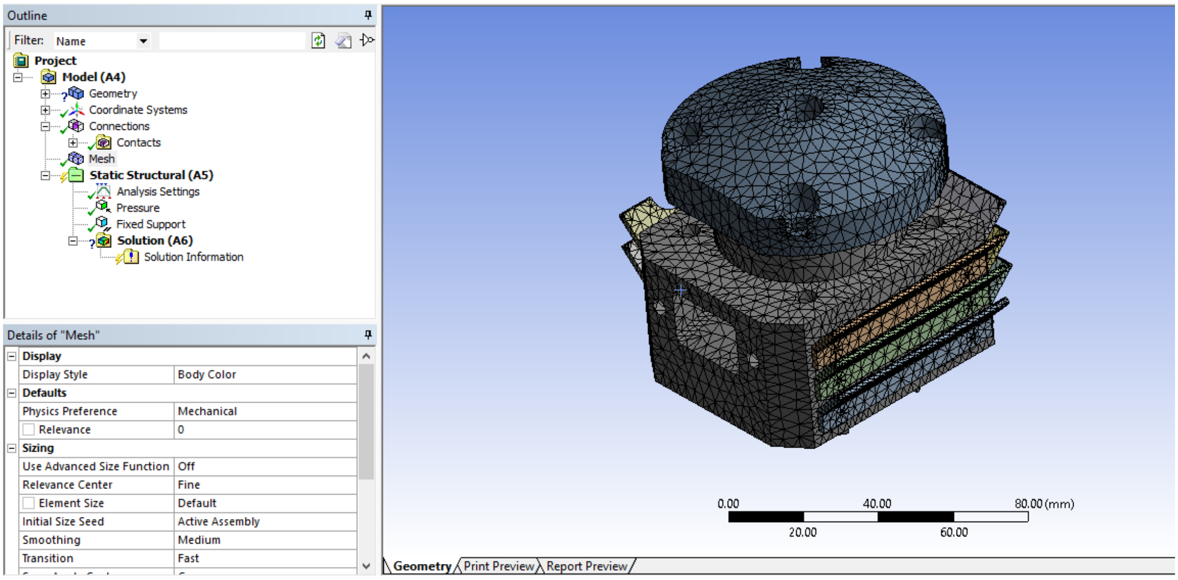


Figure 3.16: Size of fine meshing

The pressure was inserted in a static structural part as shown in Figure 3.17. The red area shows value of the pressure calculated by using a formula was set up at the inner cylinder and inner cylinder head. The fixed support also was setup in ANSYS software as shown in Figure 3.18. Besides, thermal condition characteristic also was set up in this part. The temperature value that has been taken from the experiment was set up in the thermal condition part. Figure 3.19 shows the set up of the thermal condition.

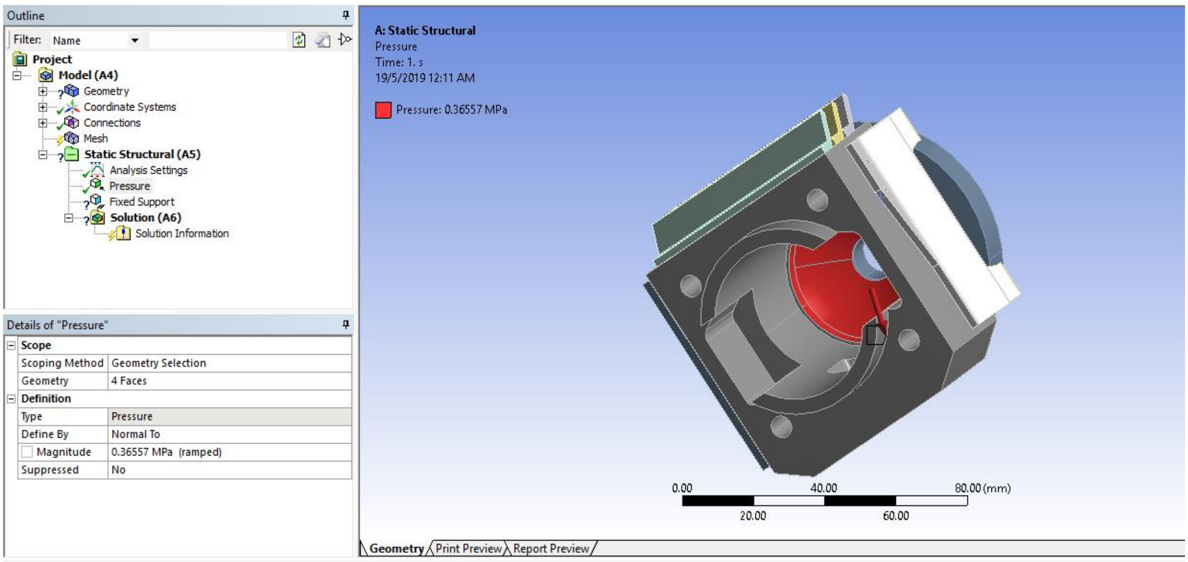


Figure 3.17: Insert setup for pressure inside the cylinder block

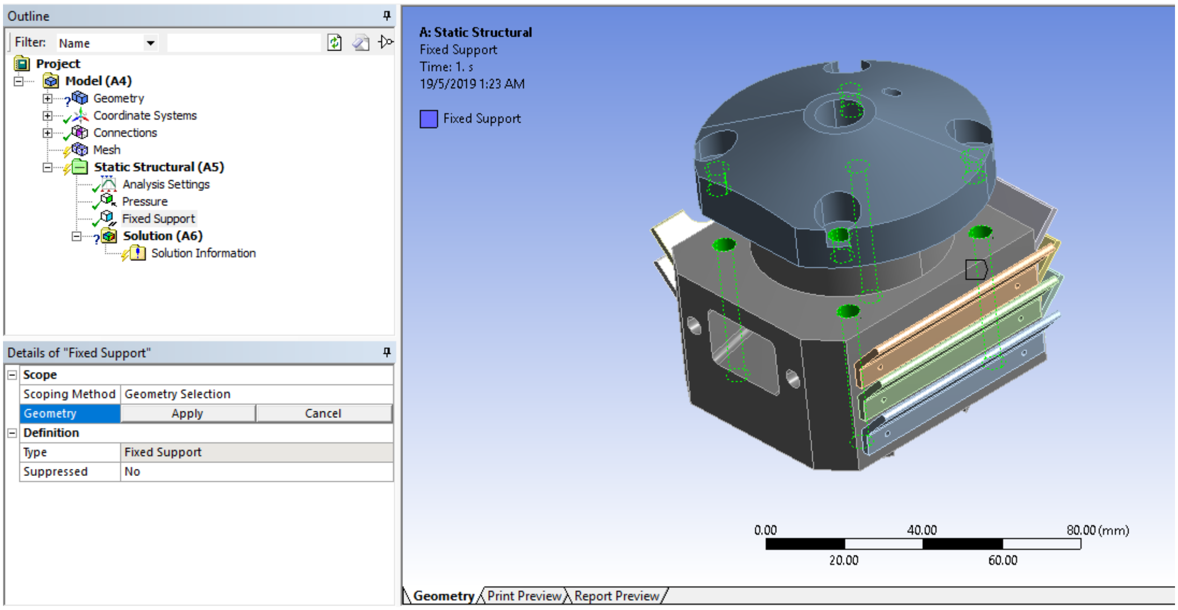


Figure 3.18: Insert setup for fixed support

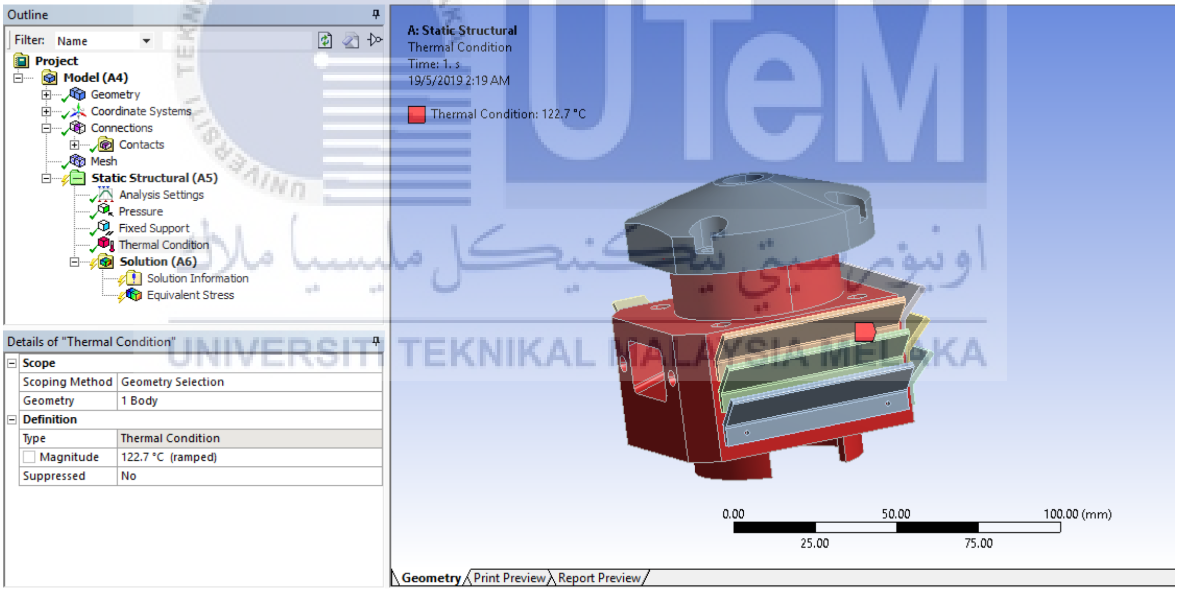


Figure 3.19: Insert setup for thermal condition at the engine block

Last but not least, the equivalent stress (Von Mises) was set in a solution part as shown in Figure 3.20. The simulation stress data has been taken at the same position where high tempreature strain gauge placed during experiment on the engine block. Figure 3.21 shows the characteristic of gray cast iron with the maximum tensile ultimate strength is 2.4E+08 Pa.

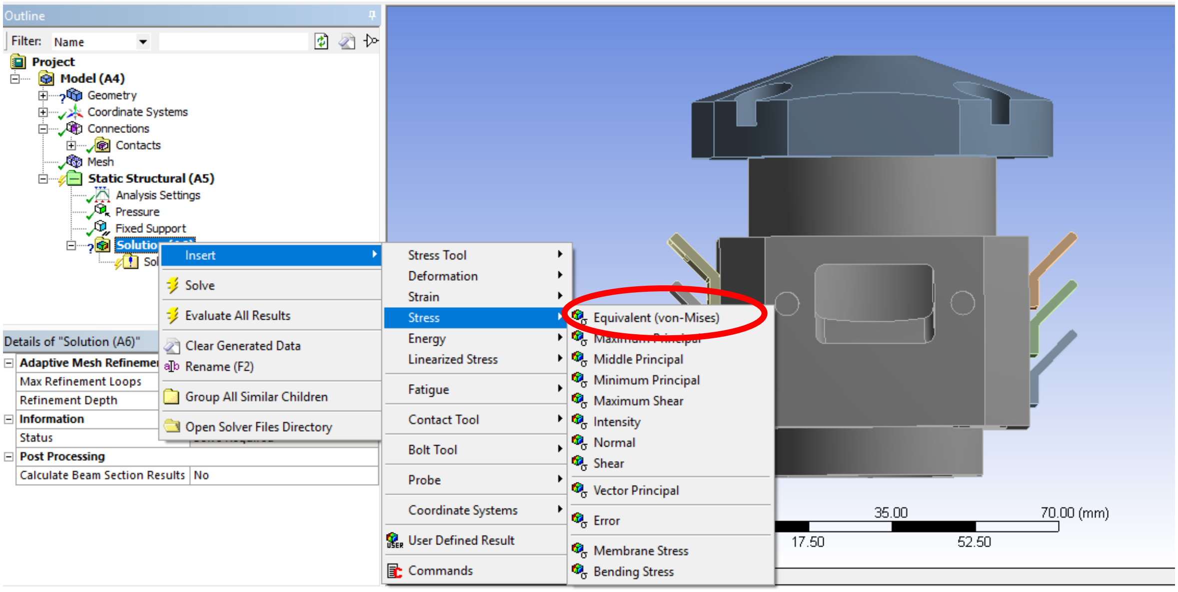


Figure 3.20: The set up for equivalent stress (von-Mises)

Properties of Outline Row 7: Gray Cast Iron

	A		B	C
1	Property		Value	Unit
3	⊞	Isotropic Secant Coefficient of Thermal Expansion		
6	⊞	Isotropic Elasticity		
16		Tensile Yield Strength	0	Pa
17		Compressive Yield Strength	0	Pa
18		Tensile Ultimate Strength	2.4E+08	Pa
19		Compressive Ultimate Strength	8.2E+08	Pa

Figure 3.21: The characteristic of gray cast iron in ANSYS software

3.5 Comparison Between Experiment and Simulation

The experimental result are based on the real time system, provides much more accurate result compared to simulation result. However, the experiment stress result was set as a fixed data. As the stress result from experiment were obtained by using theoretical calculation, the stress result will be compared with the simulation stress result.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Introduction

This chapter discusses about the data from the experiment and simulation by using ANSYS software. The temperature data from the experiment was taken by two critical point around the engine block and one from the inner combustion chamber by using thermocouple. The strain gauge is placed next to thermocouple to find a relationship between the value of the temperature and strain. The analysis result is to determine the value of stress by applying the temperature and pressure to the components.

4.2 Mathematical Theory

Most theoritical assumption regarding gases are made using the ideal gas equations. According to (Rapp, 2017), ideal gas concept is a simplification of the dynamicss of real gases, but it is sufficient in most cases to describe a number of real gases properties. Besides, strain does not have units because it is a ration of length. In calculation, stress (Pa) is typically a very large number and strain usually a very small number. The formula is applied on Equation 4.2 to find the pressure inside the combustion chamber and Equation 4.3 is to find the value of stress.

Pressure inside combustion chamber:

$$Pv = mRT \tag{4.1}$$

Assume that P_1 = 1 atm

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \tag{4.2}$$

Where; P = pressure

V = volume

T = temperature

Stress:

$$E = \frac{\sigma}{\varepsilon} \tag{4.3}$$

Where; E = Young's modulus

σ = Stress

ε = Strain

4.3 Experimental Data

4.3.1 Experiment

The data is collected by using the data logger. In this study, only the highest temperature and strain value is taken to measure the highest value of stress. The point of collected data as shown in Figure 4.1 below. The maximum temperature of the inside combustion chamber and strain reading is 122.7°C and 577με respectively. The maximum reading of the temperature inside the combustion chamber and strain has been taken to used in the calculation to get the value of stress to determined the relationship between temperature, pressure and stress.

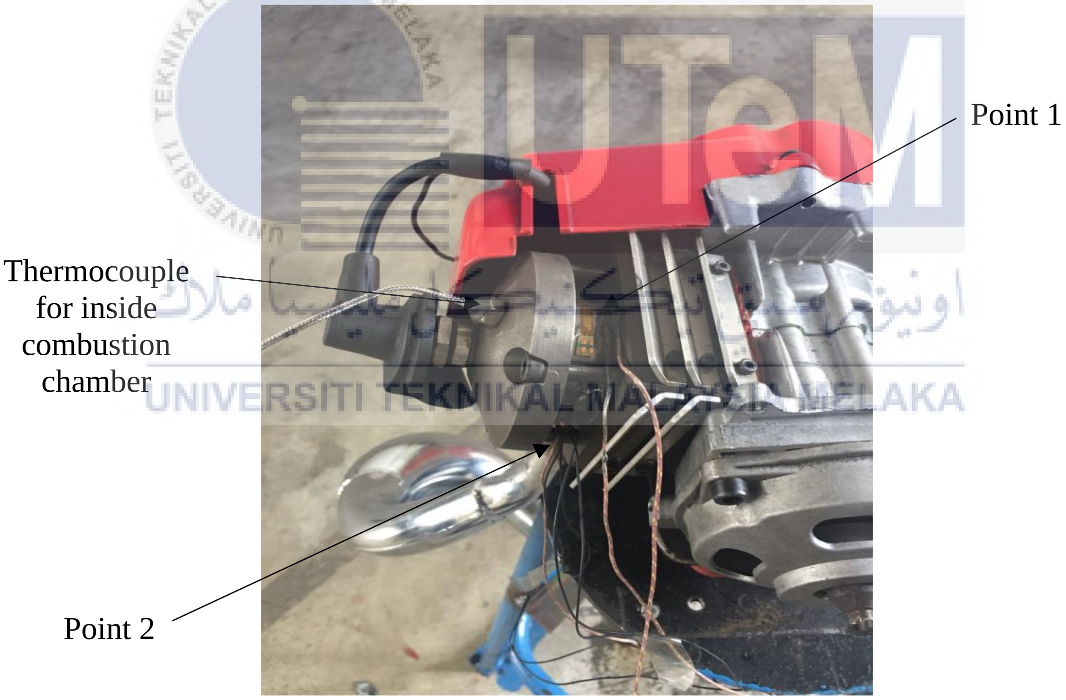


Figure 4.1: The point that the data was collected

The temperature inside the combustion chamber increase as the time of the running engine was increase due to combustion process in the cylinder block. The maximum temperature for Point 1 and Point 2 is 95.6°C and 92.9°C respectively as shown in Table 4.1. The time taken for each data is 20second.

Table 4.1: Temperature value on the engine block

Time (s)	Inside combustion chamber (°C)	Point 1 (°C)	Point 2 (°C)
0	28.7	31.2	29.8
20	73.1	62.7	61.2
40	90.8	73.9	70.9
60	106.1	84.4	81.6
80	115.3	90.1	87.5
100	120.3	94.1	91.3
120	122.7	95.6	92.9

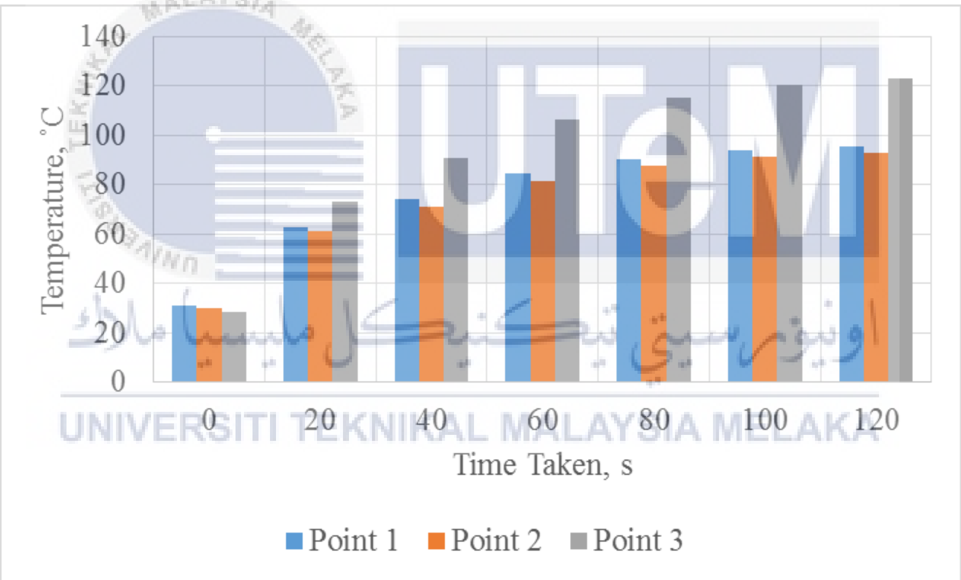


Figure 4.2: The graph temperature at the pick point

Figure 4.2 shows the graph temperature at the pick point for each 20second. The Point 3 in the figure is equal to the temperature taken inside the cylinder block. At the beginning, the temperature inside the cylinder block is lower compared to the outer cylinder block because the combustion does not occur yet. For the first 20second, the temperature inside the cylinder block was 73.1°C where the combustion occur which is more higher than the temperature for the outer cylinder block. The temperature keep increasing due to the combustion occur in the cylinder block and are also affected by time. From the graph, the trend temperature at Point 2 always lower compared with temperature at Point 1.

4.3.2 Analysis calculation

The analysis calculation has been conducted to obtain the maximum value of pressure inside the cylinder during TDC. The analysis used a Equation 4.2 to determine the value of pressure. By assuming P_1 = 1 atm and T_1 = 303K :

With value of $V_1 = 40.099x10^3$, $V_2 = 14.468x10^3$ and $T_2 = 395.7$K

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(101kPa)(40.099x10^3)}{303K} = \frac{P_2(14.468x10^3)}{395.7K}$$

Rearrange the equation :

$$P_2 = 365.57x10^3 \text{ Pa}$$

Table 4.2: The data gained from calculation and experiment.

Parameter	Value
Pressure	$365.57x10^3$ Pa
Strain	577με
Temperature	122.7°C

Table 4.2 shows the data gained from the experimental and analysis calculation. The data will be used in FEA to obtain the value of stress in simulation process.

4.4 Finite Element Result

The data gained from Table 4.2 are applied to evaluate the stress at the engine block in the ANSYS software. Figure 4.3, Figure 4.4 and Figure 4.5 shows the finite element result for coarse, medium and fine meshing respectively. In the figure, the value of stress at the same point with the experiment has been taking out by using 'probe' icon in the software. Table 4.3 show the value of stress according to the type of meshing and point taken.

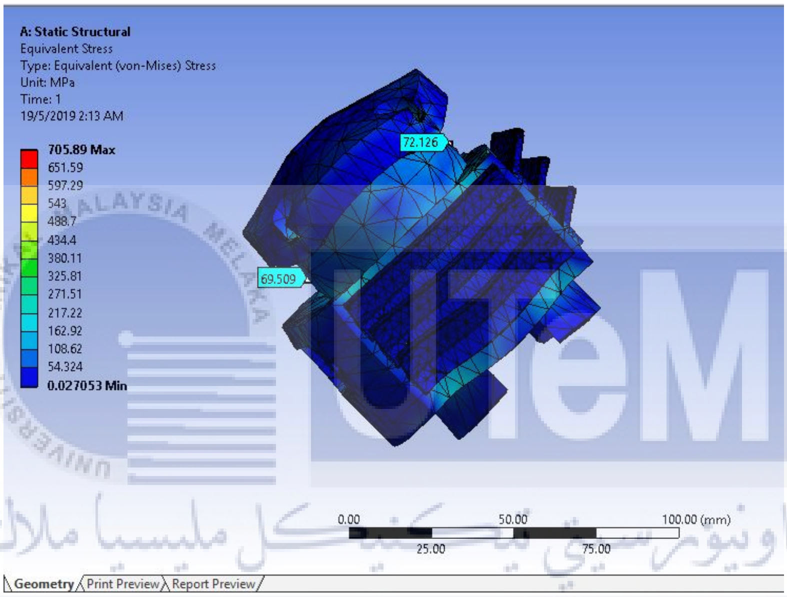


Figure 4.3: Stress result for coarse meshing type

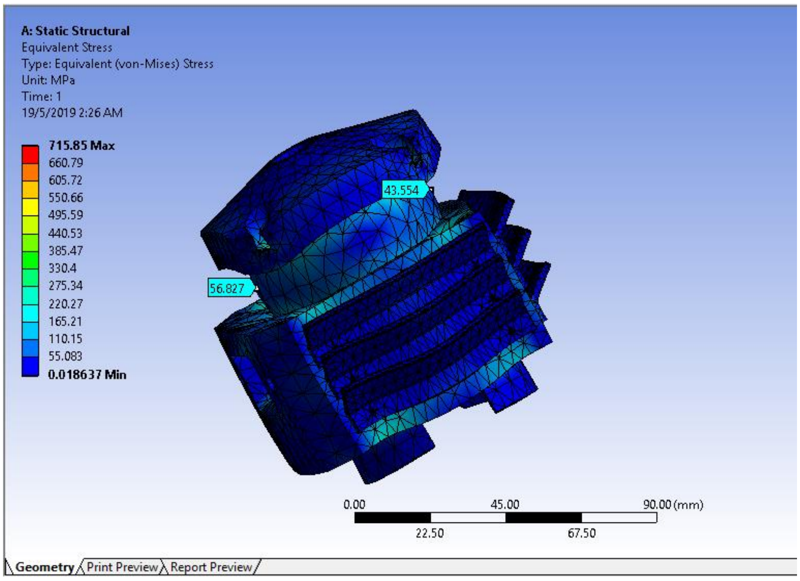


Figure 4.4: Stress result for medium meshing type

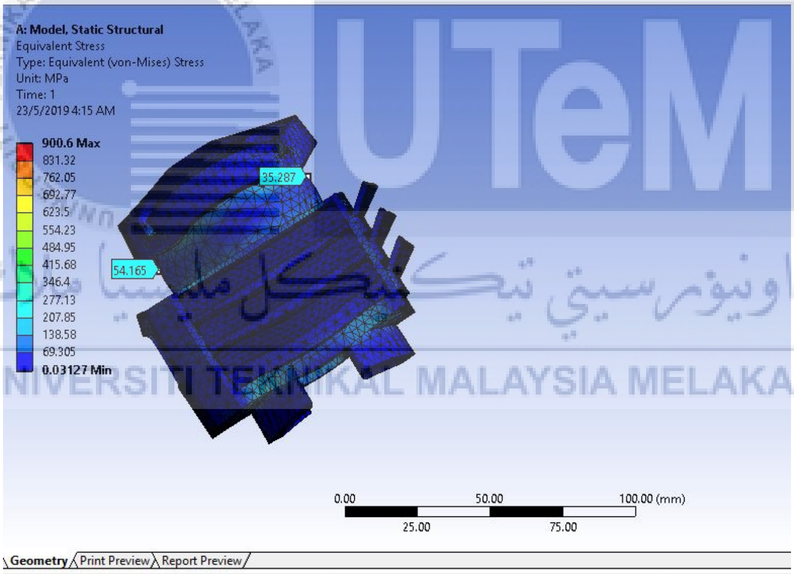


Figure 4.5: Stress result for fine meshing type

Table 4.3: The result of stress for Point 1 and Point 2

Meshing \ Point	1	2
Coarse	72.126 MPa	69.509 MPa
Medium	43.554 MPa	56.827 MPa
Fine	35.287 MPa	54.165 MPa

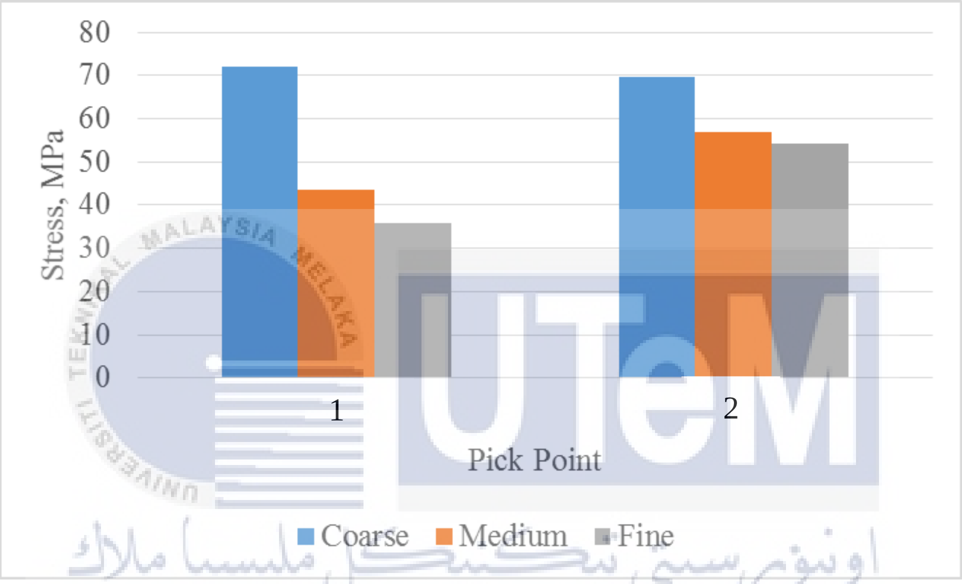


Figure 4.6: The graph comparison between point taken and type of meshing

Table 4.3 and Figure 4.6 shows the result of finite element according to the type of meshing and the place where the stress value has been taken. The type of coarse meshing at Point 1 is the highest stress value with 72.126 MPa and the lower value of stress was abtained at the Point 1 which is 35.287 MPa in fine meshing type based on ANSYS software. In medium meshing size, the value at Point 2 is more higher than Point 1 which is 56.827 MPa. At Point 2 in fine element meshing, the value of stress is 54.165 MPa which is higher than Point 1 which is 35.287 MPa. Therefore, the value will compared with the experiment stress value.

4.5 Experimental Result

According to (Dmitri, 2012), the Young's modulus value for gray cast iron ASTM 40 is 124 GPa. The Young's modulus value was used to calculate the value of stress on the engine block by using Equation 4.3 as mentioned above. The highest value of strain from the experiment times with the value of Young's modulus where the stress value on the engine block is 71.126 MPa. The result from the experiment will be compared with the fine element meshing in FEA result on ANSYS simulation which is 54.165 MPa. Table below shows the comparison between result stress and allowable stress.

Stress calculation: $E = \frac{\sigma}{\varepsilon}$

Rearrange the equation: $\sigma = E\varepsilon$

$$\sigma = (124GPa)(577\mu)$$

$$\sigma_{Exp} = 71.548x10^6\ Pa$$

	Allowable stress	Result stress
Experiment	$2.4x10^8$	$71.548x10^6$
FEA	$2.4x10^8$	$54.165x10^6$

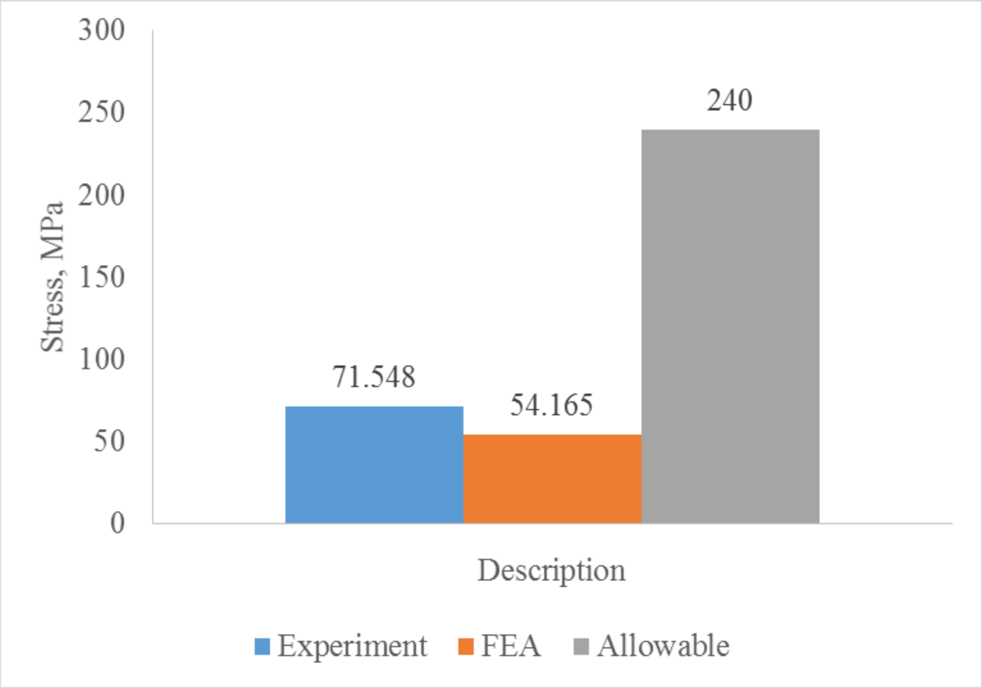


Figure 4.7: The graph comparison between experiment, FEA and allowable stress

Figure 4.7 shows the result from experiment and FEA compared to the allowable stress for gray cast iron material. The value of stress result from the experiment is higher than the value of stress from FEA. Both of the result does not exceed the maximum ultimate tensile strength value which is $2.4x10^{8}$ Pa.

4.6 Summary

In this chapter, both result for calculation and analysis part have been complied. The purpose for this chapter is to evaluate the value of stress and to show the comparison analysis between experiment and FEA. Both part do not exceed the permissible tensile strength from the data shown in analytical model. Therefore, the engine block component can be used safely.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, the pocket bike engine was used for experiment analysis at the idle speed. Based on this study, we can conclude that the value of stress increase as the temperature of the engine block increase. The drawing of the engine block, cylinder head and fin has been done by taking the dimension from the real component by using CATIA software. The purpose for this study also to evaluate the value of stress during experiment and compare the experiment result with the FEA result.

According to the analysis being made in the ANSYS software, the result shows the engine block is safe to be used. The result at both Point 1 and Point 2 does not exceed the limit which is 2.4E+08. The result is much lower to the benchmarking stress. The result from the experiment also is lower than the tensile strength limit. The excessive load beyond the material tensile strength can lead to failure. In this research also, the objective which are to determine the stress on the engine block and compare the stress value from experiment and simulation result of the engine block is achieved.

5.2 Recommedations

For this project, the study is to determine the value of stress on the engine block by using a high tempearture strain gauge and thermocouple for collect the temperature data from the engine block. The determining process of temperature can be improved in several areas in which to have a better value of temperature on the engine block. By using a vibration proof thermocouple, the exact value of temperaturecan be obtain during the engine operation. For futher study also can take a more point of stress analysis such as at cylinder head and fins. The stress value also can be obtain with variation of engine speed.

It is also necessary to improve the analysis in which known pressure in this study. Analysis can be improved by using experimental methods to find more accurate analysis of the pressure inside the engine block. There is no tools provided in this study to measure the pressure inside the engine block and due to the time limit, the experiment can not be conducted.

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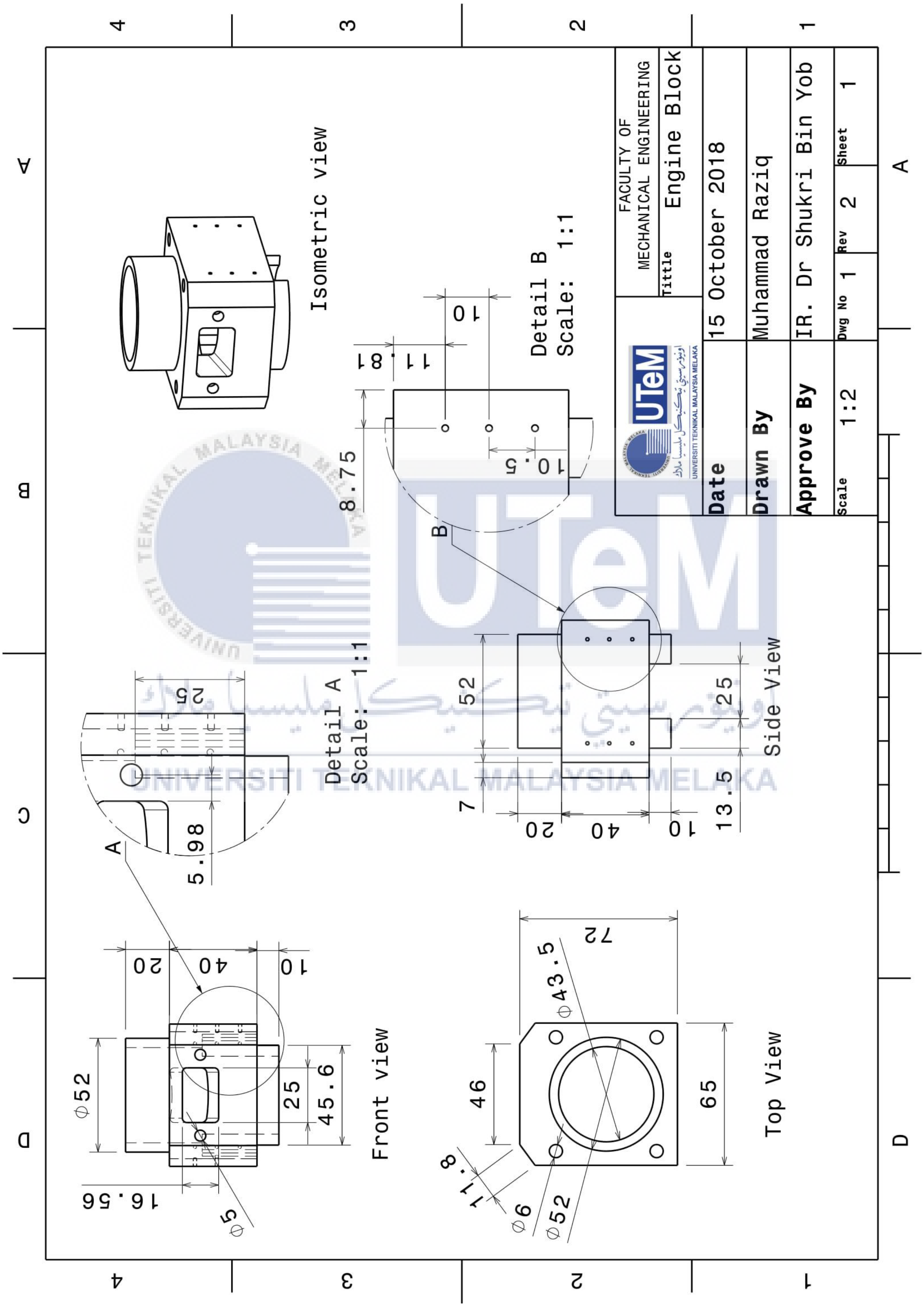
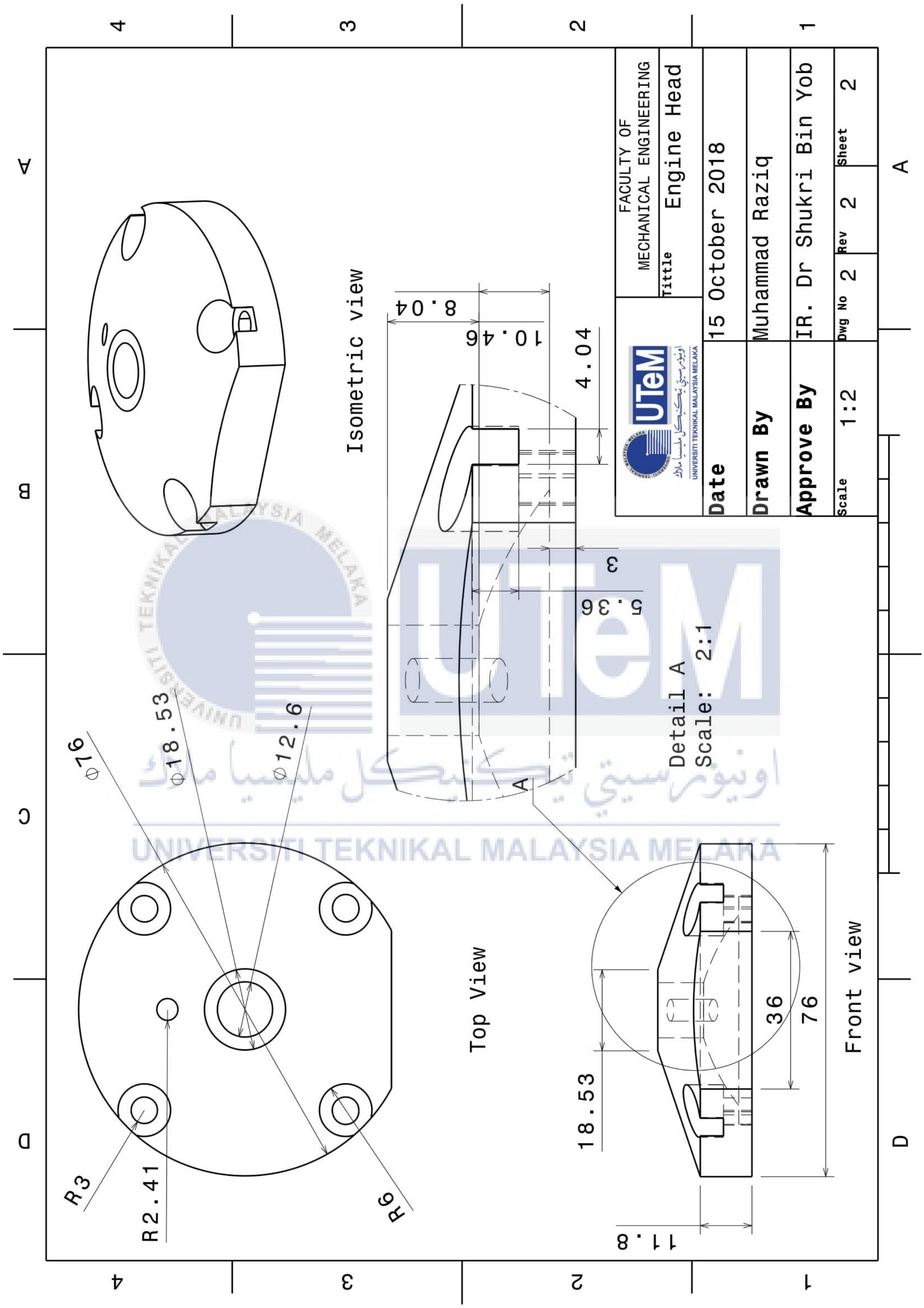
APPENDIX

Drafting Block Engine



Drafting Cylinder Head



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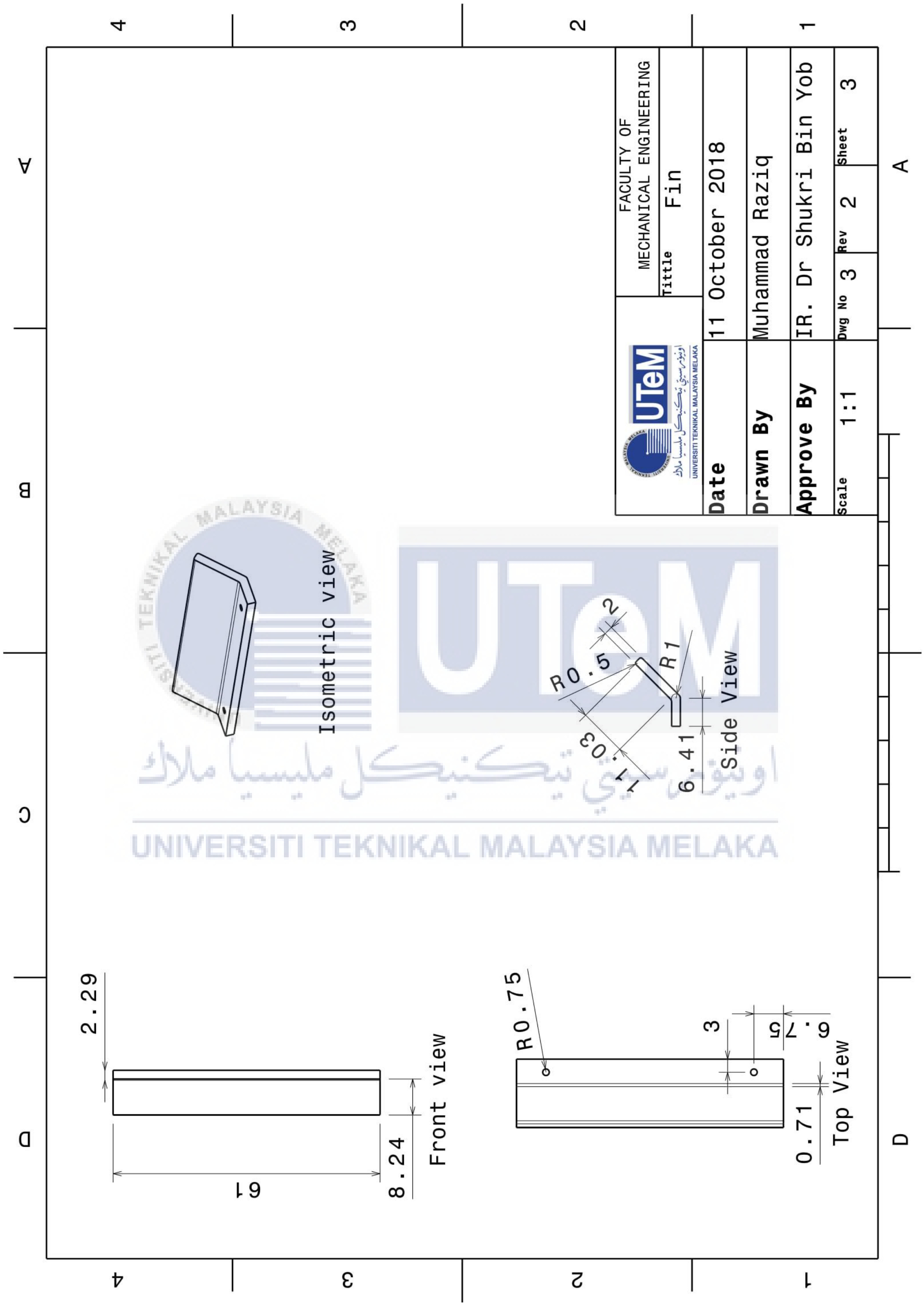

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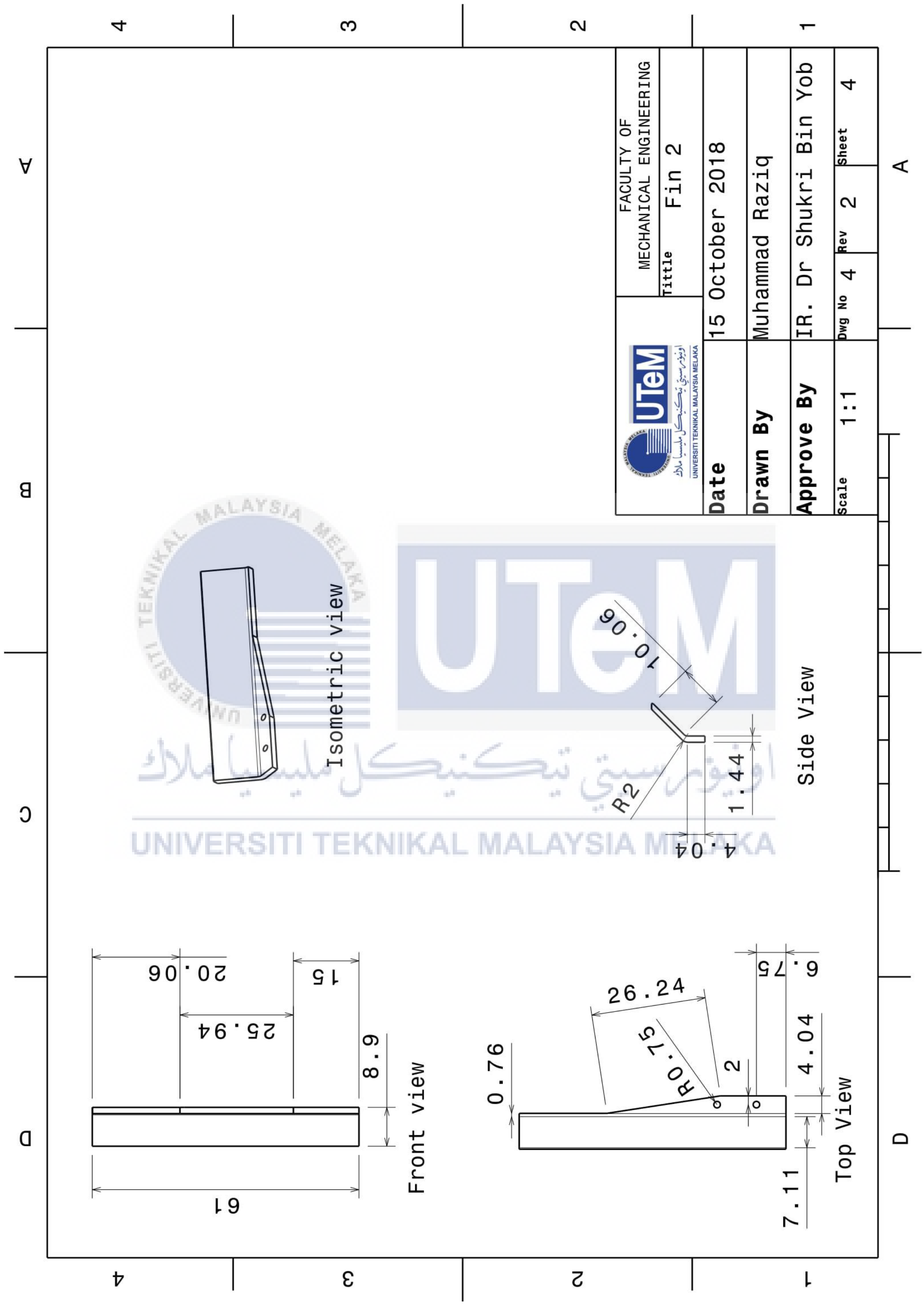

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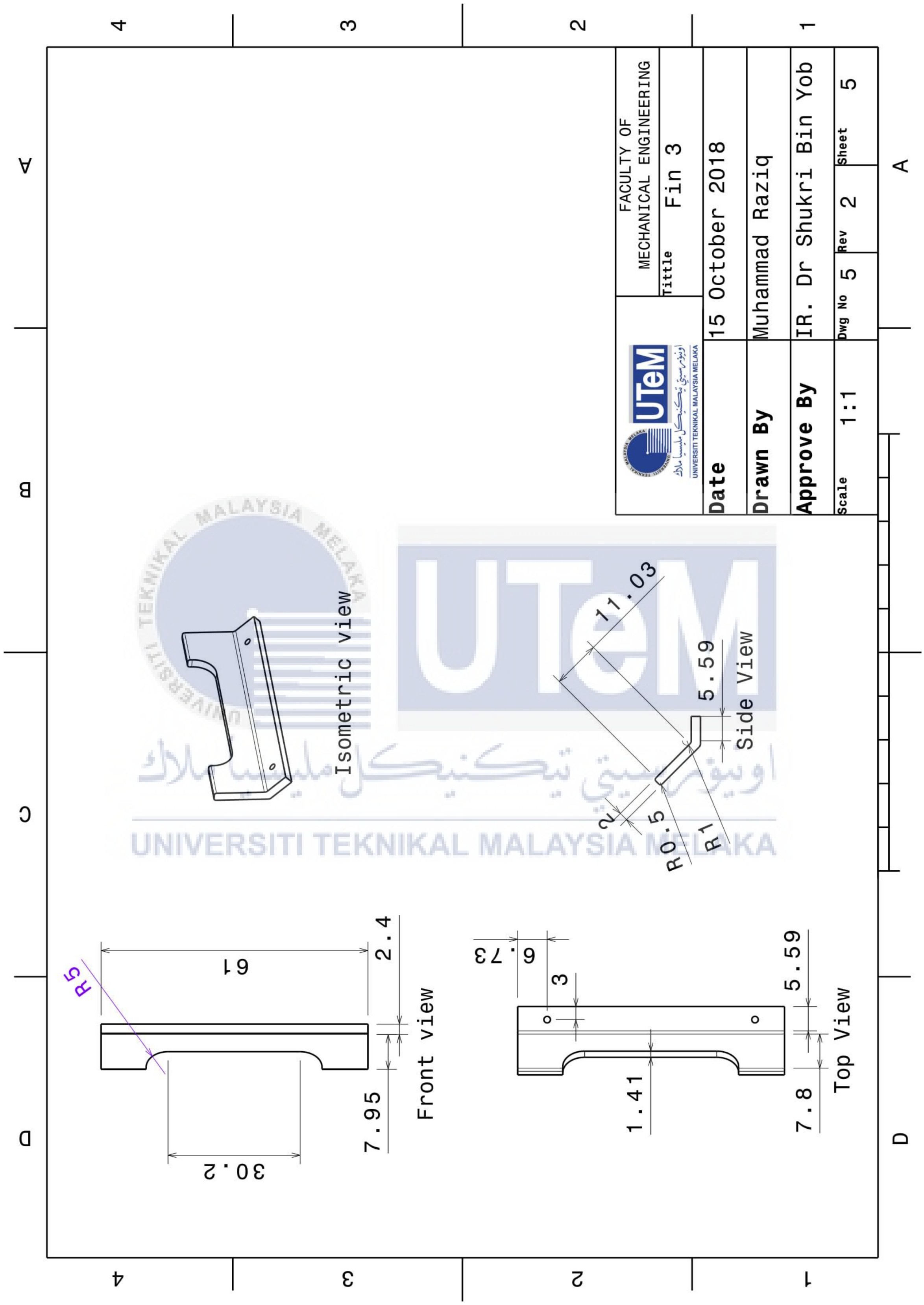

Assemble Drawing of The Engine Block