THERMAL ANALYSIS OF LIGHWEIGHT CLUTCH DISC

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SUPERVISOR DECLARATION

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DECLARATION

"I verify that this report is my own work except for the citation and quotation that the source has been clarified for each one of them"

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To my father, Zulkarnain B Hj A. Bakar, my mother, Rozimah Bte Hj Mohd Yusof, my siblings, my friends and my supervisor, Encik Fudhail bin Abdul Munir, for supporting me throughout this project and for their understanding in the way I am

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ABSTRACT

Clutch system is among the main systems inside a vehicle. Clutch is a mechanical device located between a vehicle engine and its transmission and provides mechanical coupling between the engine and transmission input shaft. Clutch system comprise of flywheel, clutch disc and friction material, pressure plate, clutch cover, diaphragm spring and the linkage necessary to operate the clutch. The clutch engages the transmission gradually by allowing a certain amount of slippage between the flywheel and the transmission input shaft. However, the slipping mechanism of the clutch generates heat energy due to friction between the clutch disc and the flywheel. At high sliding velocity, excessive frictional heat is generated which lead to high temperature rise at clutch disc surface, and this causes thermo-mechanical problem such as thermal deformations and thermo-elastic instability which can lead to thermal cracking, wear and other mode of failure of the clutch disc component. In this project, the thermal characteristic of the lightweight clutch disc is studied using FE analysis method to identify the temperature distribution at the clutch disc in steady state phase. The thermal analysis is done using ANSYS finite element software. The results provide better understanding of the clutch disc thermal characteristics and helps in developing more efficient and effective clutch disc and the clutch system in general.

ABSTRAK

Sistem pencengkam adalah antara sistem yang penting di dalam sesebuah kenderaan. Pencengkam adalah peranti mekanikal yang terletak diantara enjin kenderaan dan transmisi dan membolehkan gandingan mekanikal antara enjin dan aci input transmisi. Sistem pencengkam terdiri daripada roda tenaga, cakera pencengkam dan bahan geseran, plat tekanan, penutup pencengkam, spring diafragma dan penyambungan yang sesuai untuk pencengkam itu beroperasi. Pencengkam bergabung dengan transmisi secara perlahana-lahan dengan membenarkan sedikit pergelinciran antara roda tenaga dan aci input transmisi. Walau bagaimanapun, mekanisma pergelinciran cakera pencengkam menghasilkan haba disebabkan geseran antara cakera pencengkam dan roda tenaga. Pada kelajuan yang tinggi, haba yang berlebihan terhasil dimana ia akan meningkatkan suhu pada permukaan cakera pencengkam, dan menyebabkan masalah termo-mekanikal seperti perubahan haba dan termo-elastik yang membawa kepada keretakan haba, haus dan masalah lain yang boleh timbul. Dalam projek ini, ciri-ciri termo cakera pencengkam dipelajari menggunakan analisis FE untuk mengenalpasti rata haba pada cakera pencengkam ketika fasa kukuh. Analisis termo dilakukan menggunakan perisian ANSYS. Hasilnya akan menyediakan pemahaman yang lebih terhadap ciri-ciri termo cakera pencengkam dan membantu dalam menghasilkan cakera pencengkam yang lebih efisyen dan efektif seterusnya di dalam sistem pencengkam itu sendiri.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

A clutch is a mechanical device for quickly and easily connecting or disconnecting a pair of rotating coaxial shafts. It is usually placed between the driving motor and the input shaft to a machine, permitting the engine to be started in an unloaded stage. Single plate, dry clutch is among the popular type of clutches in use (Lee and Cho 2006). Mechanical clutches fall into two main categories which is positive engagement and progressive engagement (Garret et al. 2001).

1.2 OBJECTIVE

The objectives of this project are:

1. To study the thermal capacity of the clutch disc.
2. To determine the temperature distribution on the clutch countermate disc in steady state and transient condition.

1.3 SCOPE

The scopes of this proposed project are:

1. To generate 3-dimensional geometry model of the commercial clutch disc component.
2. To perform steady state thermal analysis on the model to determine the temperature distribution of the component under steady state component using ANSYS.
3. To compare thermal analysis between carbon-carbon composite and commercial (gray cast iron) material of clutch disc.

1.4 PROBLEM STATEMENT

Clutch failure and damage due to excessive frictional heat and heat fluctuations to the clutch countermate disc often happens to any type of automotive clutches. This situation contribute to thermal fatigue to the component which cause the clutch countermate disc to crack and deform. This later will create problems such as clutch slip, clutch drag or failure of clutch to disengage properly and clutch rattling as well as shortening the lifecycle of the component.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF CLUTCH DEVELOPMENT

In 1885, it was reported that when Karl Friedrich Benz has invented the first commercial gas powered automobile, the famous Trip-Cycle, he also was the first person to invent and use the clutch system to the car .Exedy Corp., one of the major players for clutch technology, which manufactured clutches under the brand name of Exedy and Daikin, with the plate and spline hub secured by rivets (Daikin Clutch, 2011). Until now, clutch manufactures has come out with new and efficient technologies for clutch system to compensate higher torque produced by bigger engine created especially for heavy vehicles.

2.2 AUTOMOTIVE CLUTCH MECHANISM

Automotive clutches are located between the engine and the tranmission. It provides mechanical coupling between the engine and transmission input shaft. Manual tranmission cars need a clutch to enable engaging and disengaging the transmission. The clutch engages the transmission gradually by allowing a certain amount of slippage between the flywheel and the transmission input shaft (Erjavcc 2005). Clutch basically consists of six major parts: flywheel, clutch disc, pressure plate, diaphragm spring, clutch cover and the linkage necessary to operate the clutch (Lee and Cho 2006).

The flywheel and the pressure plate are the drive components of the clutch. The flywheel is connected to the engine crankshaft, while the clutch disc and the pressure plate are connected to the transmission input shaft. When a clutch is disengaged (clutch pedal release), the flywheel rotates independently as according to the engine rotation, and the engine (clutch pedal pressed), the pressure plate moves towards the flywheel and pushed the clutch disc towards the flywheel, causing both components rotating together at same speed and connecting the engine to the transmission shaft. This mechanism enables gear shifting and engine idling when the car stopped.

Component	Description
Flywheel	The flywheel is normally made from nodular or grey cast iron, which has a high graphite content to lubricate the clutch when is engaged. The rear surface of the flywheel is a friction surface and machined very flat to ensure smooth clutch engagement. The flywheel absorbed the torsional vibration cause by the crankshaft,

	and provides inertia to rotate the crankshaft.
Clutch Disc	The clutch disc receives the rotating motion from the flywheel and transfer the motion to the transmission input shaft. **A** clutch disc comprise of grey cast iron countermate disc, friction facing, and cushioning springs. The friction facing is the main component in contact with the flywheel, and provides the required friction force to maintain that contact. It is either riveted or bonded to the disc. The cushioning spring, or torsional springs, cause the contact pressure of the facings to rise gradually as the springs flatten out when the clutch is engage. It also eliminates chatter during engagement and avoiding the flywheel and pressure plate sticking to the clutch disc when disengaging the clutch.
Pressure Plate	Pressure plate acts to push the clutch disc onto the flywheel with sufficient force to transmit engine torque efficiently and move away from the clutch disc to stop rotating it. There are two type of pressure plate assembly, either using coil springs or diaphragm spring. Both types are usually have stamped steel cover and bolted to the flywheel, and also act as a housing holding the parts together. The assembly differs in the mechanism of pushing and drawing

	back the pressure plate from the clutch disc.
Clutch Release Bearing	The clutch release bearing or throw-out bearing is a sealed and prelubricated ball bearing. It smoothly and quietly moves the pressure plate release levers or diaphragm spring when the clutch is engage and disengage. The release bearing is mounted on a hub made from iron casting that slides on a hollow shaft at the front of the transmission housing.
Clutch Fork	The clutch fork function is to move the release bearing and hub back and forth during clutch engagement and disengagement. It is a forked lever that pivots on a ball stud at the opening in the bell housing. The fork end connects the clutch linkage and clutch pedal.
Clutch Linkage	Clutch linkage connects the clutch pedal to the clutch fork. It enables drivers to control the engage and disengage operation of a clutch system smoothly with minimum force. There are four types of clutch linkage available, which is the cable linkage, self adjusting clutch linkage, hydraulic clutch linkage and internal slave cylinders.

Table 1: Main components of a clutch disc (Erjavec, 2005)

2.3 CLUTCH DISC DESCRIPTION

The clutch countermate disc used in this project is a part of a diaphragm spring dry clutch dry disc system, which is normally used in commercial passenger vehicles. The clutch countermate disc is located between the clutch friction facing and the clutch cushioning plate. The clutch cushioning spring is a plate where is acts to absorb the vibration effect during clutch engagement as well as linking the clutch countermate disc and the clutch disc base together. In the overall clutch disc assembly, rivets and pins are normally used to attach all the components together. The clutch countermate disc functions as the base to firmly hold the clutch friction facing. A basic construction of the overall clutch disc assembly is shown in figure 1 below.

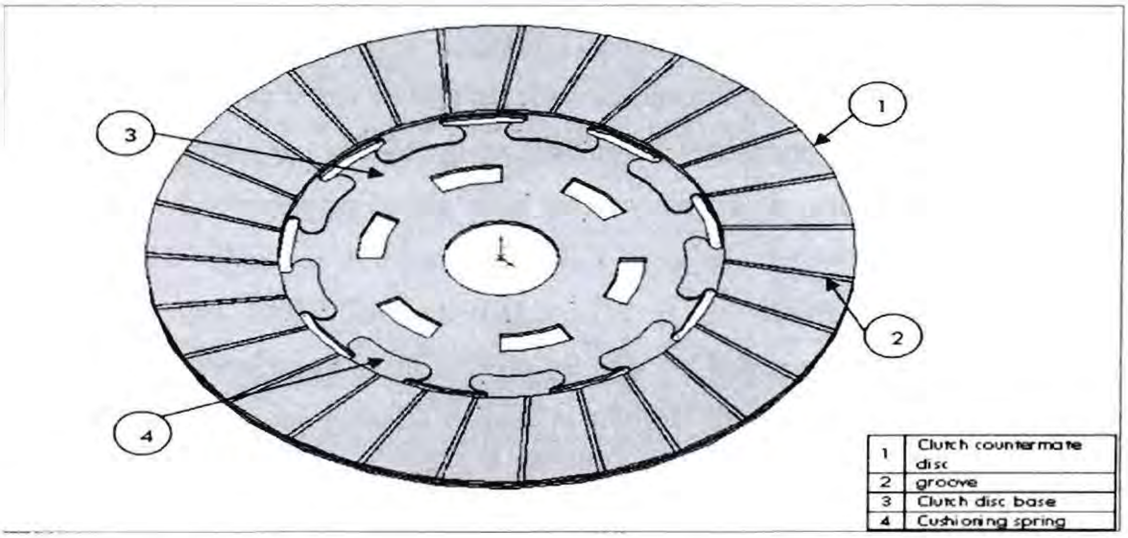


Figure 1: basic clutch disc assembly (Ridzuan Mansor, 2007)

2.4 THEORY OF HEAT TRANSFER

Heat transfer is the study of thermal energy transfer rate between material bodies as a result of temperature difference. There are three types of heat transfer method, which are through conduction, convection and radiation. A rough explanation of each heat transfer mode is stated below.

2.4.1 Conduction

Conduction is the transfer of thermal energy through a solid or fluid due to a temperature gradient (Huebner et al. 2001). The transfer of thermal energy occurs at the molecular and atomic levels without net mass motion of the material. Conduction takes place in solid, liquid and gases. In gases and liquids, conduction is due to collisions and diffusion of the molecules during their random motion. In solids, it it due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons (Cengel, 2003). Conduction also called as the transfer of energy from the more energetic particles of a substance to the adjacent less energetic one as a result of interactions between the particles (Yunus A. Cengel, 2011). This process can happen during solid, liquid or gases condition.

The rate equation describing conduction heat transfer mode is Fourier's law. For isotropic medium Fourier's law is (Huebner et al. 2001)

$$q = - k \frac{\partial T}{\partial n}$$

where q is the rate of heat flow per unit area in the ***n*** direction, k is the thermal conductivity that may be a function of the temperature T, and *n* indicates a normal direction. The minus sign appears because positive thermal energy transfer occurs from a warmer to a colder region; that is, the temperature gradient $\partial T / \partial n$ is negative in the direction of positive heat flow. Similarly, the Fourier's law for conduction can be simplified as (Cengel, 2003)

$$q_{\text{cond}} = kA\frac{T1-T2}{\Delta x} = -kA\frac{\Delta T}{\Delta x}$$

where ***A*** is the area, ΔT is the temperature difference and Δx is the thickness/length difference.

2.4.2 Convection

Convection is mode of energy transfer between a solid surface and the adjacent liquid or gas that is in the motion, and it involves the combined effects of conduction of fluid motion (Yunus A. Cengel, 2011). In other words, convection is the transfer of thermal energy through a fluid due to motion of the fluid and the energy transfer from one fluid particle to another occurs by conduction, but thermal energy is transported by the motion of the fluid. The transfer energy is called forced convection when the fluid motion is caused by external mechanical means. When the fluid motion is caused by density differences in fluid (buoyant effects), it is called free or natural. Several characteristic of non-dimensional convective of heat transfer such as Reynolds number, Prandtl number and Nusselt number.

The Reynolds number state the ratio of inertia forces to viscous forces in a viscous flow. For example, the transition from laminar to turbulent flow in forced convection. While the Prandtl number state a measure of the ratio of viscous diffusion to therma diffusion. For example, in hydrodynamic and thermally developing flows the Prandtl number is a measure of the rate at which velocity and temperature profile develops. The Nusselt number state that a dimensionless convection coefficient used in both free and forced convection. For forced convection low-speed flows, the Nusselt number is expressed in terms of the Reynolds and Prandtl number. The Nusselt number is considered as Mach number when forced convection high-speed flows.

i. Reynolds number: $\mathrm{Re} = \frac{\rho U L}{\mu}$

ii. Prandtl number: $\mathrm{Pr} = \frac{\mu C p}{k}$

iii. Nusselt number: $\mathrm{Nu} = \frac{h L}{k}$

Where ρ is density, U is characteristic flow velocity, L is a characteristic length, μ is viscosity, Cp is specific heat at constant pressure, k is thermal conductivity and h is a convective coefficient.

The rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling (Cengel 2003).

$$q_{conv} = hA(T_s - T_\infty)$$

where h is the convection heat transfer coefficient, A is the surface area through which convection occurs, T_s is the surface temperature and T_∞ is the temperature of the fluid sufficiently far from the surface. Note that at the surface, the fluid temperature equals the surface temperature of the solid.

2.4.3 Radiation

Energy emitted by matter in the form of electromagnetic waves as a result of the changes in the electronic configurations of the atoms or moleculs is a radiation of heat transfer (Yunus A. Cengel, 2011). The electromagnetic radiation spectrum ranges from cosmic rays with wavelengths less than 10^{-12} m to radio waves with wavelengths of 10^4 m, and thermal radiation occupies the portion of the spectrum between 10^{-7} m and 10^{-4} that is detected as heat or light. The thermal radiation wavelength range includes the ultraviolet, visible and infrared sub-ranges. Radiation heat transfer differs from conduction in two important ways. For conduction and convection, transfer of energy between two locations typically depends on the temperature difference between the two locations. Radiation heat transfer however typically depends on the difference of the absolute temperature of the individual locations, each raised to the fourth power. The second distinguishing feature of radiation is that no medium is required for radiation heat transfer to occur. In conduction and convection, heat transfer thermal energy is transported by physical medium, but radiant energy will pass through a perfect vacuum.

The maximum rate of radiation heat that can be emitted from a surface at an absolute temperature T_s is given by Stefan-Boltzmann law as (Cengel, 2003)

$$q_{\text{emit,max}} = \sigma A_s T_s^4$$

where σ = 5.67x10-8 W/m2*K^4 is the Stefan Boltzmannconstant, A is the surface area through radiation occurs and T is the absolute temperature of the body. The idealized surface for this condition is called the blackbody. However, the radiation emitted by all real surfaces is less than the radiation emitted by the blackbody at the same temperature, and is expressed as (Cengel, 2003)

$$q_{\text{emit}} = \varepsilon \sigma A_s T_s^{\,4}$$

where ε is the emissivity of the surface.

2.5 HEAT TRANSFER FORMULATION IN FINITE ELEMENT

2.5.1 Thermal Steady State

For a thermal steady state (time-independent) condition, the global FE equation is given as

$$K_T T = Q$$

where matrix K_T depends on the conductivity of the material, T is a vector of node point temperature of the solid body and Q is a vector of thermal loads. The convection and radiation boundary conditions, if present, will contribute terms to both K_T and Q. In linear problems, K_T is only regarded as a matrix constant instead of a function of temperature in non-linear problems.

Similarly, further added that for linear steady state condition with includes the effect of conduction and convection (Huebner et al. 2001), the finite element formulation is expressed as

$$[[K_c] + [K_h]]\{T\} = \{R_Q\} + \{R_q\} + \{R_h\}$$

Where $\{R_Q\}$, $\{R_q\}$ and $\{R_h\}$ are heat load vectors arising from internal heat generation, specified surface heating and surface convection respectively. The coefficient matrices $[K_c]$ and $[K_h]$ are element conductance matrices and relate to conduction and convection, respectively. The convection matrix is computed only for elements with surface convection. $\{T\}$ is the element nodal temperature

By implying the above equations using FE software, the nodal temperature and temperature distribution for the body can be determined. The nodal temperature values can be later used for stress analysis to determine the thermal stress generated from the steady state condition.

2.5.2 Thermal Transient

Transient condition involved time dependent function of the heat transfer analysis. In transient condition, temperature change in a unit volume of material is resisted by thermal mass that depends on the mass density ρ of the material and its specific heat c (Cook, 1995). He stated that for transient condition, the finite element formulation can be expressed as

$$K_T T + C\dot{T} = Q \qquad \text{where } Q = Q(t)$$

in which $\dot{T} = \delta T/\delta t$. In general, thermal loads Q are time dependent and matrix C may be called a heat capacity matrix. For linear conditions, (Cook, 1995) further stated that equation above can be written in the form of

$$K_T T_n + C\dot{T}_n = Q_n$$

where n is the nth instance of time, all Q, K_T and C are time dependent.

Huebner et al. (2001) also further elaborated the basic linear transient analysis for finite element formulation by adding the effect of conductance and convection. The linear transient analysis can also be expressed as (Huebner et al. 2001)

$$[C]\{\dot{T}(t)\} + [[K_c] + [K_h(t)]]\{T(t)\} = \{R_Q(t) + \{R_q(t)\} + \{R_h(t)\}$$

where *[C]* is the coefficient matrix of the time derivative of the nodal temperatures or the element capacitance matrix, (t) indicates the function of time in transient condition and {T(t)} is the vector of element nodal temperature. Again, $\{R_Q\}$, $\{R_q)$ and $\{R_h\}$ are heat load vectors arising from internal heat generation, specified surface heating and surface convection respectively and the coefficient matrices $[K_c]$ and $[K_h]$ are element conductance matrices and relate to conduction and convection, respectively.

2.6 THERMAL BEHAVIOUR OF AUTOMOTIVE FRICTION CLUTCH

Friction clutch especially in thermal capacity have been studied for many years using numerous researched but now researches in multiple fields. The automotive clutches generate heat from the rubbed surface due to the power dissipation by frcitional slip between flywheel and clutch disc and between the clutch disc and pressure plate (Lee and Cho 2006). When the members of a machine are initially at rest are brought up to speed, slipping must occur in the clutch until the driven members have the same speed as the driver (Shigley 1986). Kinetic energy is absorbed during slippage of a clutch, and this energy appears as heat. Temperature rise occurs when heat is generated faster than it is dissipated (Shigley 1986).

The generated heat has a considerable influence on the efficiency of the clutch and it is important to keep the clutch under some critical temperautre ranges. Otherwise, the overheated clutch could fail or work at a very low efficiency. Therefore, assessment of the clutch thermal capacity is essential especially in the early stage of its design (Lee and Cho 2006).

However, due to the rush towards higher performance has increased sliding operative speeds of clutches and other sliding system such as brakes (Afferante et al. 2003). Increase of sliding spped resulted in the increase of frictional heat generated during clutch engagement. Excessive frictional heat may create thermal distortion and deformation on the clutch disc contact surface. Thermal distortions of friction disc caused by frictional heating modify pressure distribution on friction surface. Pressure distributions, in turn, determine distribution of generated frcitional heat. These interdependencies create a complex thermoelastic system that, under some conditions, may become unstable and may lead to severe pressure concentrations with very high local temperature and stress. This phenomenon is responsible for many common thermal failure modes of friction elements and is known as frictionally excited thermoelastic instability (Zagrodzki and Farris 1998).

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

In general, there are two main components that were performed in this project. The first component is to develop a 3-dimensional model of the clutch disc, followed by performing finite element analysis using commercial finite element (FE) software to study the thermal capacity of the commercial clutch disc as shown in figure below:

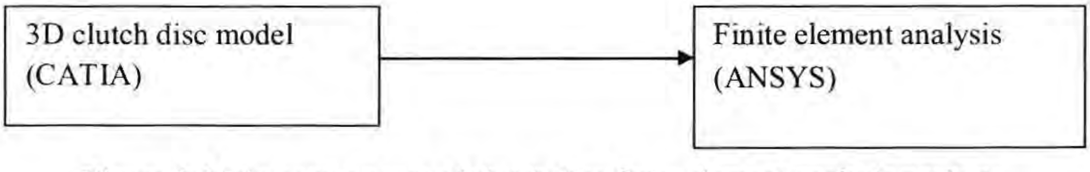


Figure 2: Main components of clutch disc finite element analysis project

3.2 FINITE ELEMENT ANALYSIS

The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in almost every industry. In more and more engineering situations today, find that it is necessary to obtain approximate solutions to problem rather than exact closed form solution.
It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provide approximate, but acceptable solutions. The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It has been developed simultaneously with the increasing use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations.

3.3 DESIGNING THE CLUTCH DISC

This project started with designing the clutch disc completely. At the end of this project, I have completely designed the model of clutch disc. To design this model, CATIA software was used and have to considered this following criteria:

- Sizing of the clutch disc
  - Diameter
  - Thickness
  - Diameter outlet = 160 mm
  - Diameter inlet = 90 mm
- Configuration
- Disc plate
- Material = carbon-carbon composite

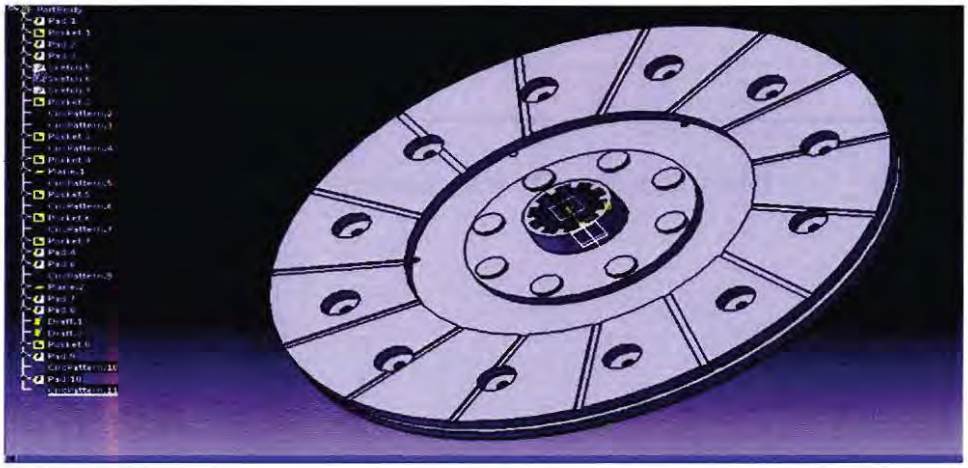


Figure 3: CAE model of clutch disc

The 3-dimensional clutch disc model developed is imported into the finite element analysis software as its FE geometry model based on actual dimensions of the commercial clutch disc. Then the isometrical view is made out to show the diameter, thickness and scale of the clutch disc model. Isometrical view can be divided to 3 view, which is bottom view, top view and right or left view as follow:

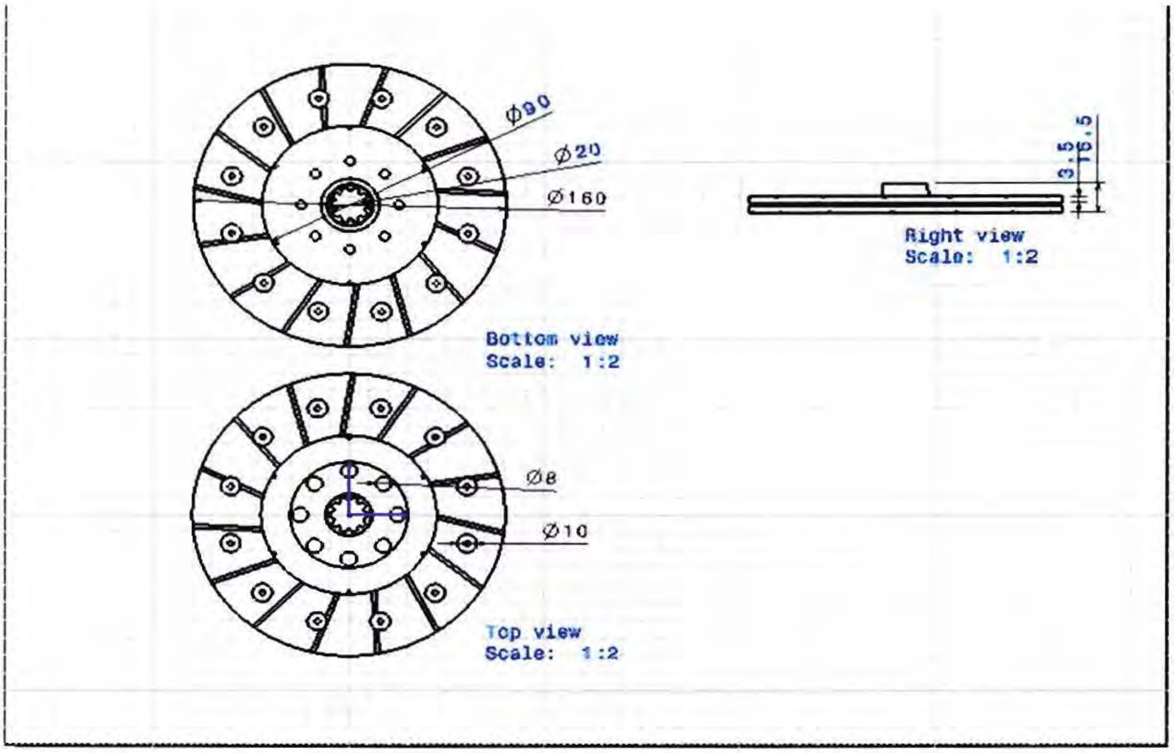


Figure 4: Isometric view of clutch disc model

3.4 MATERIAL SELECTION

Carbon-carbon composite are more advanced from a carbon and consist of a fiber based on carbon precursors embedded in a carbon matrix. This material also are family of advanced composite materials. This material have a certain properties such as low density, high thermal conductivity, low thermal espansion and modulus. Carbon-carbon composite mostly used in aerospace applications, mainly for aircraft disc brake and for parts of rocket nozzles (Torsten. W & Gordon B, 1997) due to its special properties.

3.4.1 Carbon-Carbon Composite Properties

Carbon-carbon composites have the capability of stuctural integrity at temperature above 1000 °C. This material has a very high thermal conductivity, 12-15 times higher in the fiber direction than perpendicular to the fiber (John, D.B & Dan, D.E 1993). This properties are very important to considered during this project. These are some material properties of carbon-carbon composites for thermal analysis in this project.

Young's Modulus	9.5E+10 Pa
Poisson Ratio	0.32
Isotropic Thermal Conductivity	51 W/m*C
Density	$1.80\text{x}10^3$ Kg/m^3
Specific Heat	1420 J/Kg*C
Maximum Temperature	350 °C – 450 °C

Table 2: Properties of Carbon-Carbon Composite (Samir Sfarni, 2009)

3.5 THERMAL ANALYSIS

A thermal analysis calculates the temperature distribution and related thermal quantities in brake disc. Typical thermal quantities are:

i. The temperature distribution
ii. The amount of heat lost or gained
iii. Thermal fluxes

3.5.1 Type of Thermal Analysis

1. A steady state thermal analysis determines the temperature distribution and other thermal quantities under steady state loading conditions. A steady state loading condition is a situation where heat storage effects varying over a period of time can be ignored.

2. A transient thermal analysis determines the temperature distribution and other thermal quantities under conditions that varying over a period of time.

3.6 MESHING

Meshing consists of semi-permeable barrier made of connected strands of metal, fiber, or other flexible or ductile material. Mesh is similar to web or net in that it has many attached or woven strands. Subdivision surface, in the field of 3D computer graphics, is a method of representing a smooth surface via the specification of a coarser piecewise linear polygon mesh. The smooth surface can be calculated from the coarse mesh as the limit of a recursive process of subdividing each polygonal face into smaller faces that better approximate the smooth surface. The function of meshing is to calculate the critical area of the part or surface when the temperature is applied. It is will calculate the every meshing area with details information about the thermal distribution and it is will notify if the part is failure when the temperature is applied.

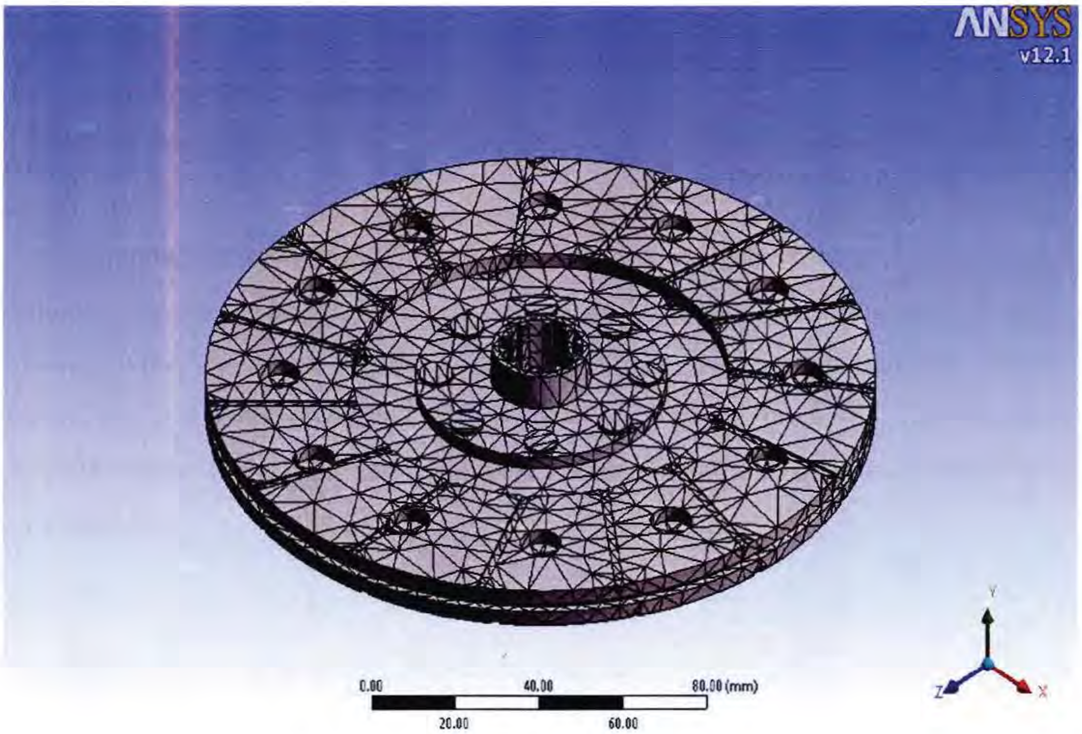


Figure 5: Meshing of the clutch disc

CHAPTER 4

RESULT AND DISCUSSION

4.1 BOUNDARY CONDITION

Boundary condition is the surface where the analysis is done. In this case, the boundary condition of the clutch disc is located at the surface where the clutch disc mate is facing with the pressure plate. So, there are 2 boundary conditions, which is temperature and convection and the 2 kind of material have the same boundary condition. Below is the boundary condition for carbon-carbon composites and gray cast iron material.

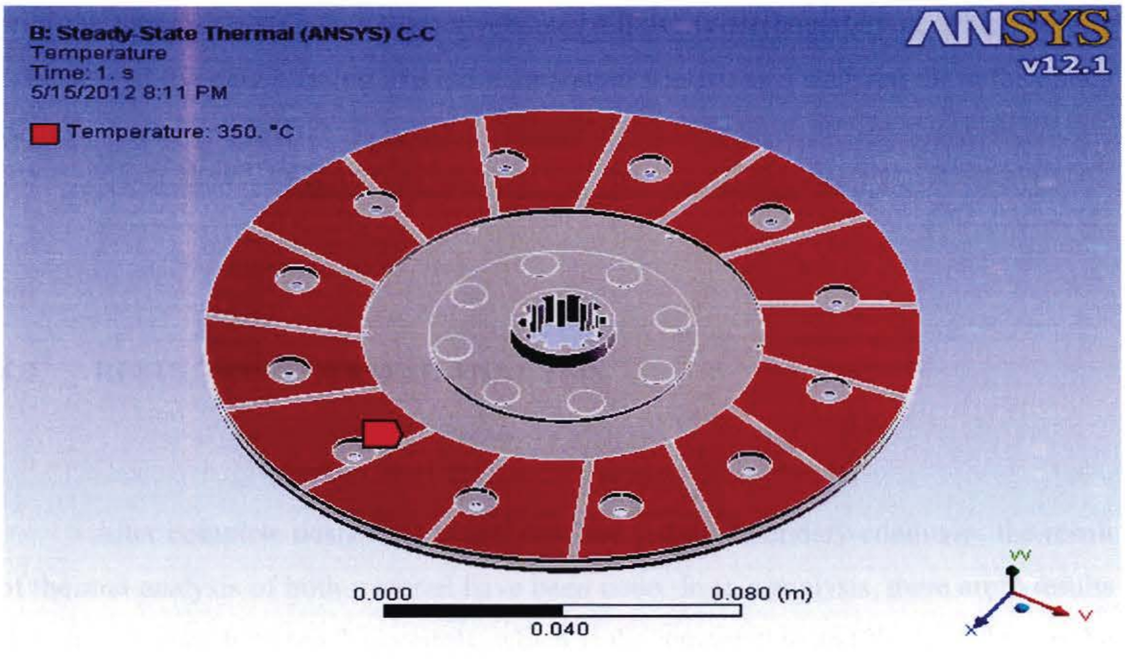


Figure 6: Boundary condition of temperature

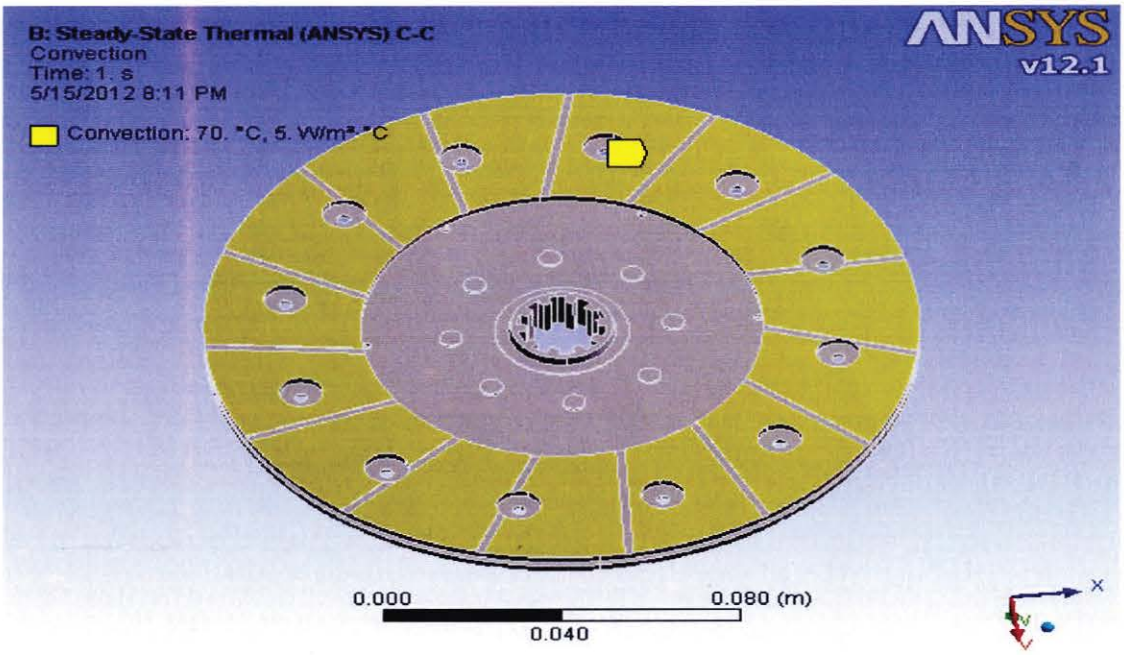


Figure 7: Boundary condition of convection

From figure above, the temperature (red) is the boundary condition that faces with the pressure plate while the convection (yellow) is the boundary condition for the back side of the clutch facing and the temperature was set as a stagnant air in the clutch casing.

4.2 RESULT OF THERMAL ANALYSIS

After complete design the clutch disc and put the boundary condition, the result of thermal analysis of both material have been done. In this analysis, there are 2 results that can compare between 2 materials, which is the temperature and the heat flux on the clutch disc.

4.2.1 Carbon-Carbon Composites - Temperature

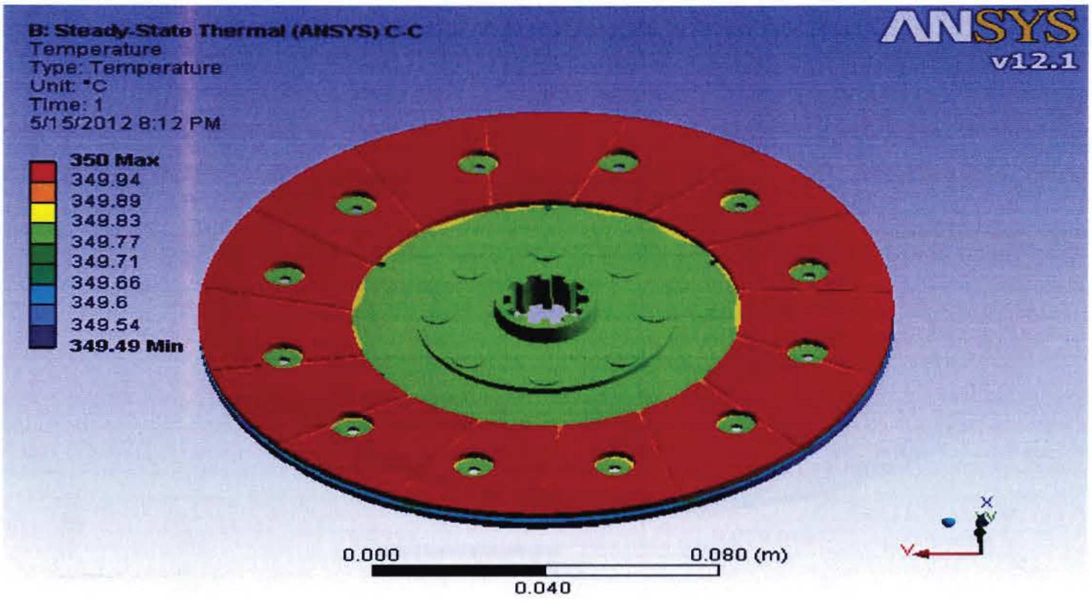


Figure 8: Front view of carbon-carbon composite

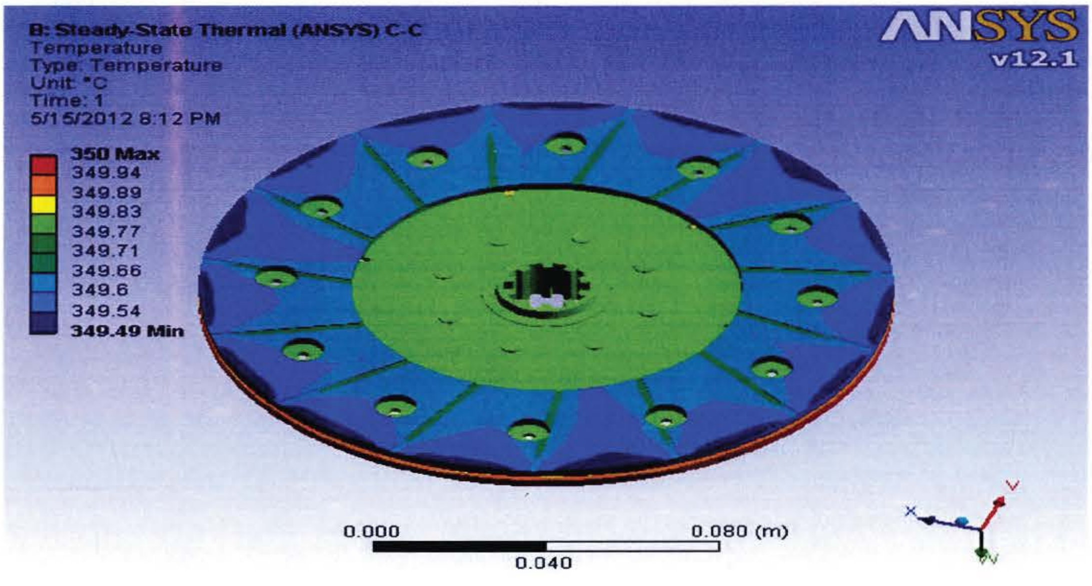


Figure 9: Rear view carbon-carbon composite

4.2.2 Gray Cast Iron – Temperature

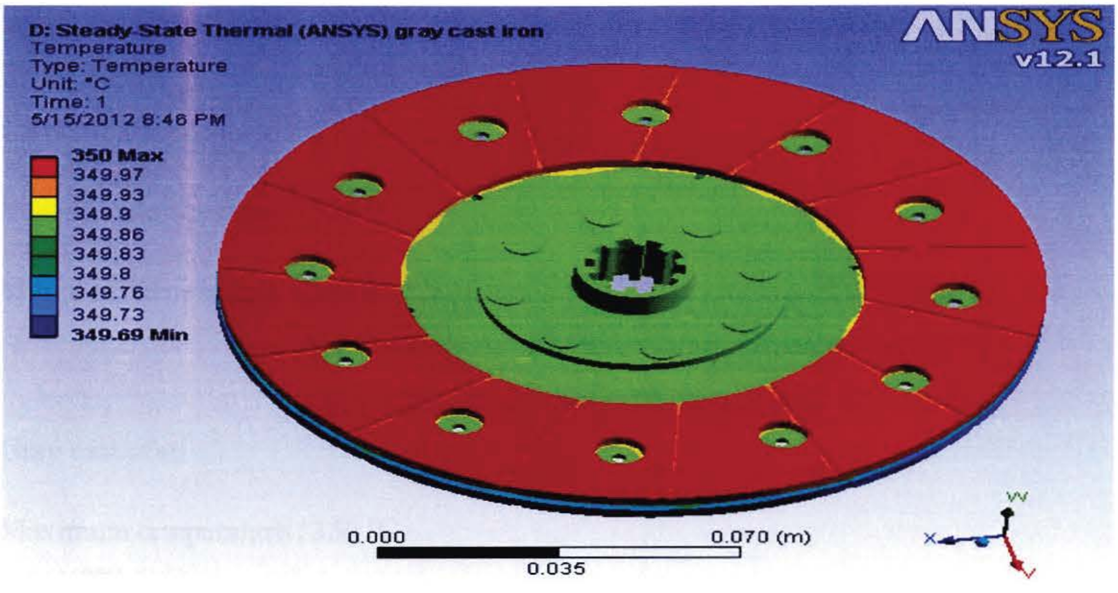


Figure 10: Front view of gray cast iron

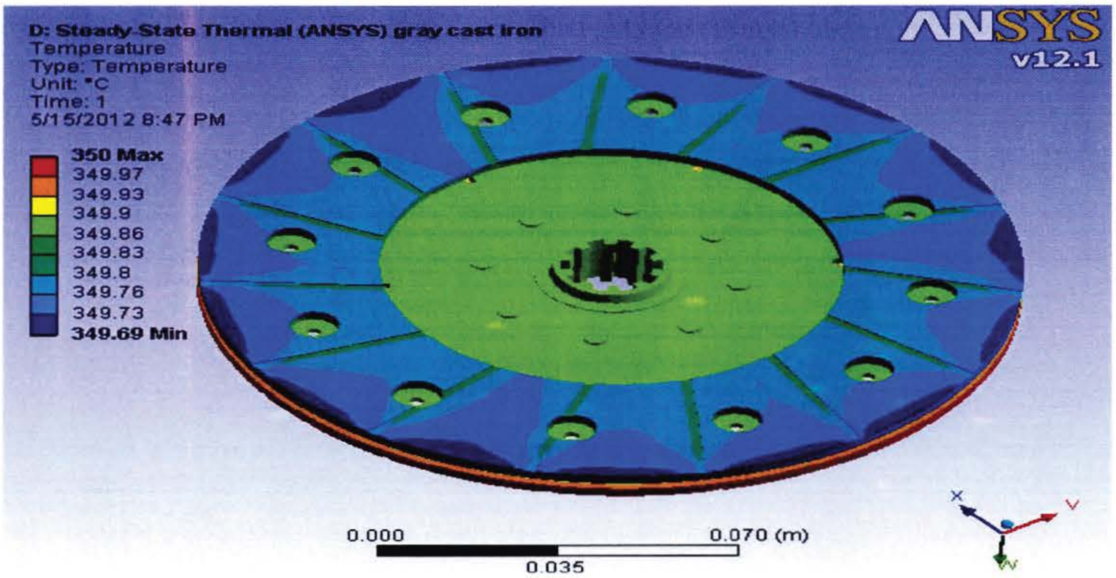


Figure 11: Rear view of gray cast iron

So, from the design and the distribution of the temperature, it is almost same between the 2 material. But, there are some different which is the temperature and we can compare the maximum and minimum of the temperature.

Carbon-carbon composite:

Maximum temperature : 350 °C

Minimum temperature : 349.49 °C

Gray cast iron:

Maximum temperature : 350 °C

Minimum temperature : 349.69 °C

There is a different temperature between the 2 material which is the carbon-carbon composite have a low temperature than gray cast iron and.

4.2.3 Carbon-Carbon Composite – Total heat flux

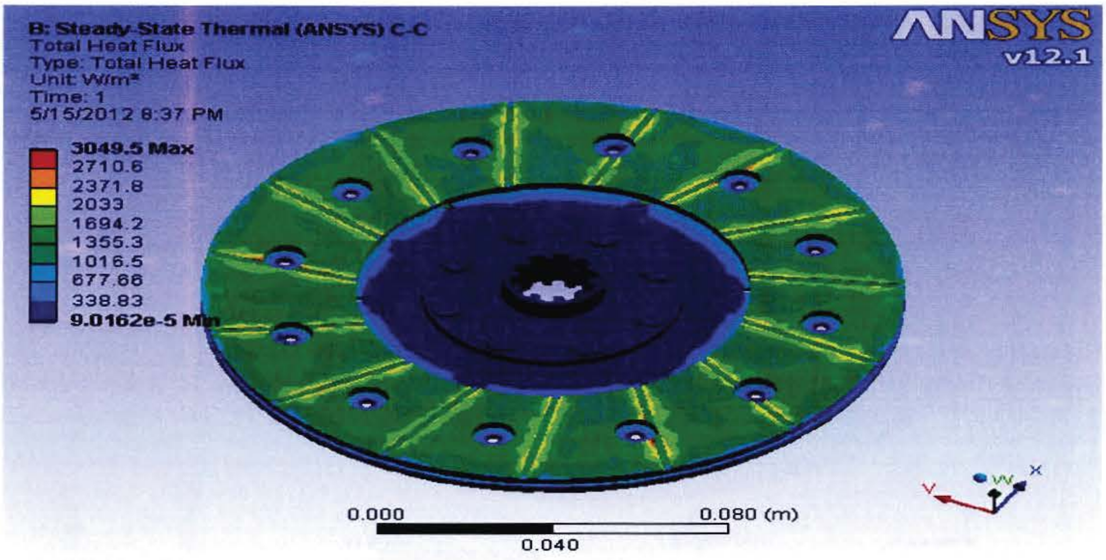


Figure 12: Front view of carbon-carbon composite

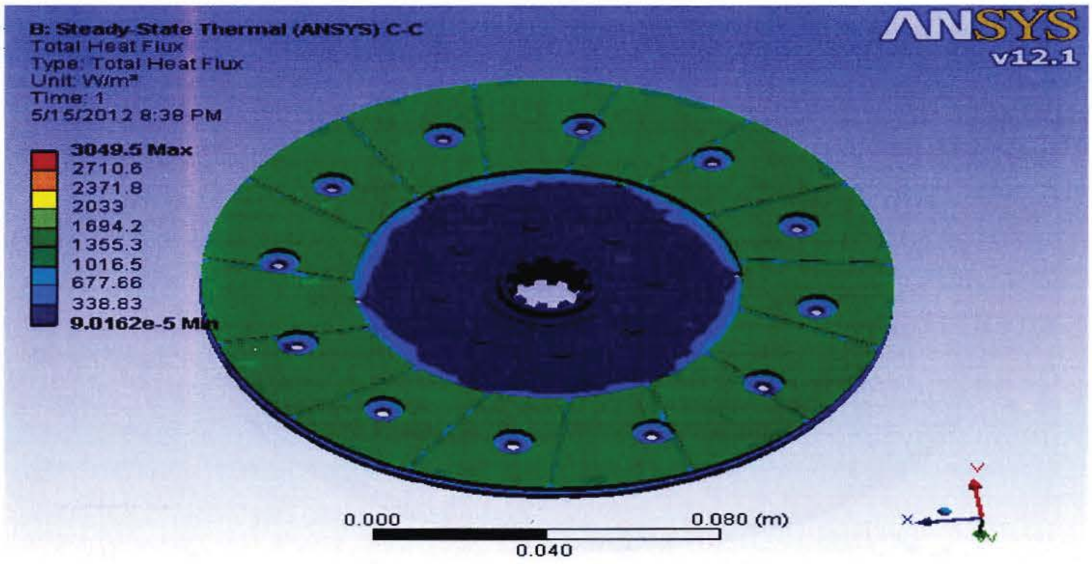


Figure 13: Rear view of carbon-carbon composite

4.2.4 Gray Cast Iron – Total heat flux

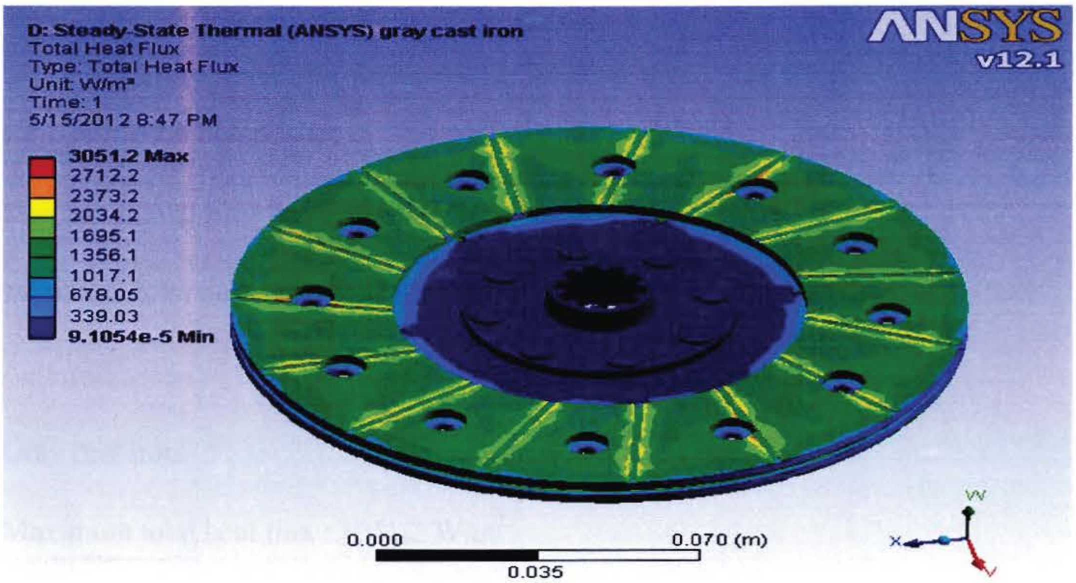


Figure 14: Front view of gray cast iron

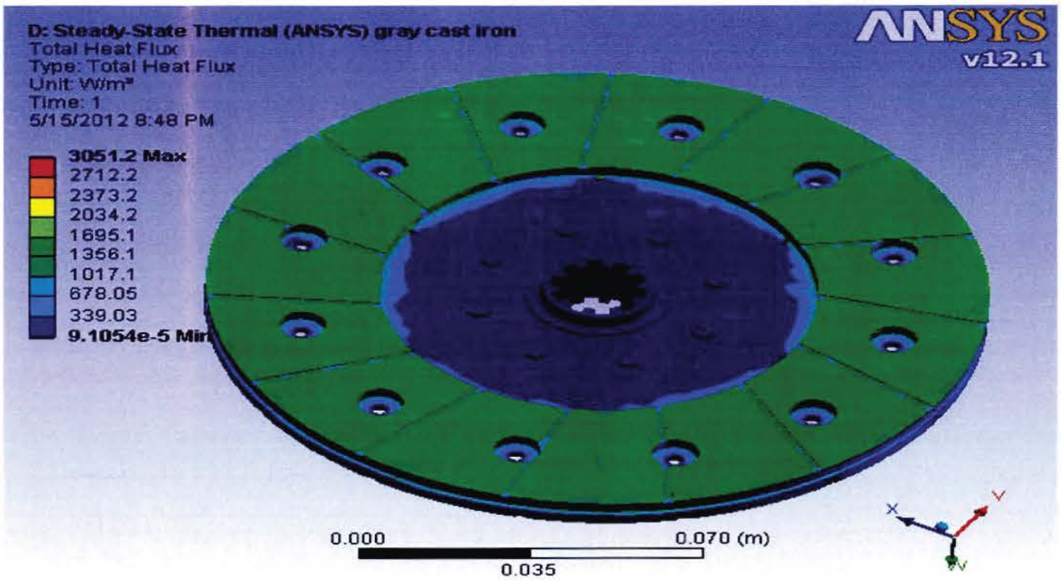


Figure 15: Rear view of gray cast iron

So, from the design and the distribution of the total heat flux, it is almost same between the 2 material. But, there are some different which is the total heat flux and we can compare the maximum and minimum of the total heat flux.

Carbon-carbon composite:

Maximum total heat flux : 3049.65 W/m^2

Minimum total heat flux : $9.0162e^{-5}$ W/m^2

Gray cast iron:

Maximum total heat flux : 3051.2 W/m^2

Minimum total heat flux : $9.1054e^{-5}$ W/m^2

For a more detail of total heat flux, next is the vector of heat flux where the flow of heat through the clutch disc.

4.2.5 CarbonCcarbon Composite – Vector of Heat Flux

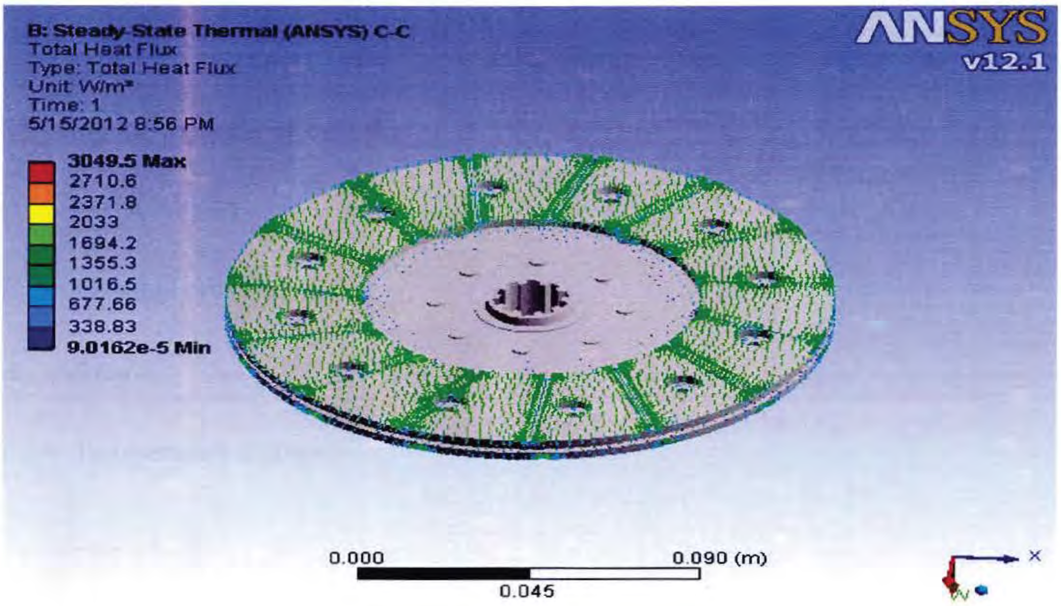


Figure 16: Vector total heat flux of carbon-carbon composite

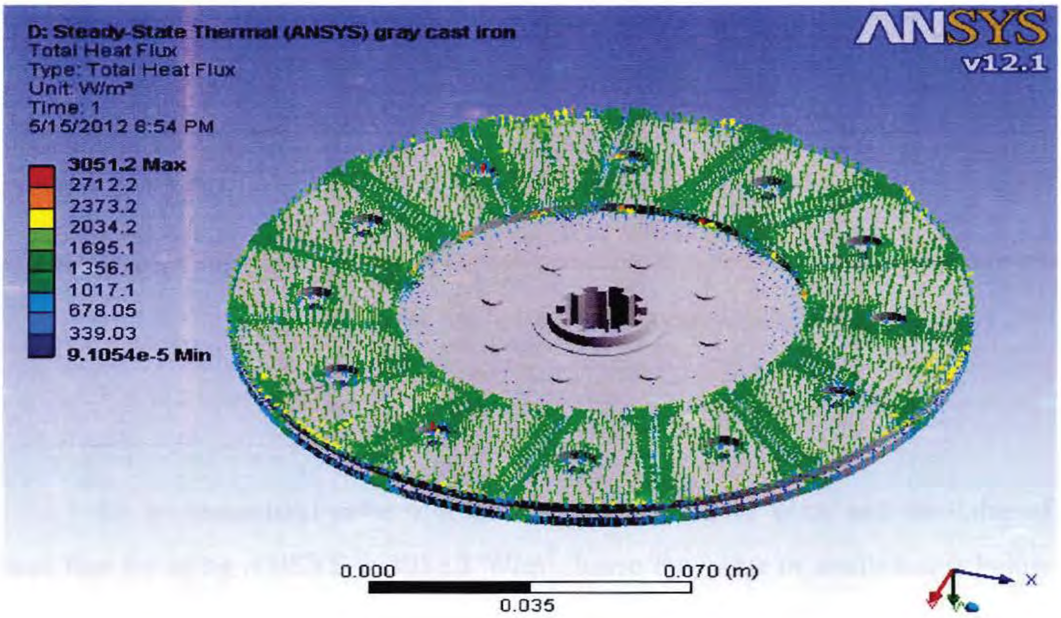


Figure 17: Vector total heat flux of gray cast iron

From the picture above, the vector of total heat flux for gray cast iron (commercial) is more than carbon-carbon composites because of the isotropic thermal conductivity differential between the 2 of material.

So using the formula of heat flux,

$Q = K * A * (\Delta T)$

K = Thermal conductivity

A = Area

ΔT = Temperature different

For carbon-carbon composite material,

$K = 51\ W/m^{o}C$

$A = 0.3195\ m$

$\Delta T = 350\ ^{o}C - 70\ ^{o}C = 280\ ^{o}C$

$$
\begin{aligned}
Q &= K * A * (\Delta T) \\
&= 51\ W/m^{o}C * 0.3195\ m * 280\ ^{o}C \\
&= 4562.46\ W/m^{2}
\end{aligned}
$$

So, by theoretical value of total heat flux is 4562.46 W/m^2 and the value of total heat flux by using ANSYS is 3051.2 W/m^2. Since the value of analytical is below than the value of theoretical, it show that this part is safe to use and failure will not occur.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

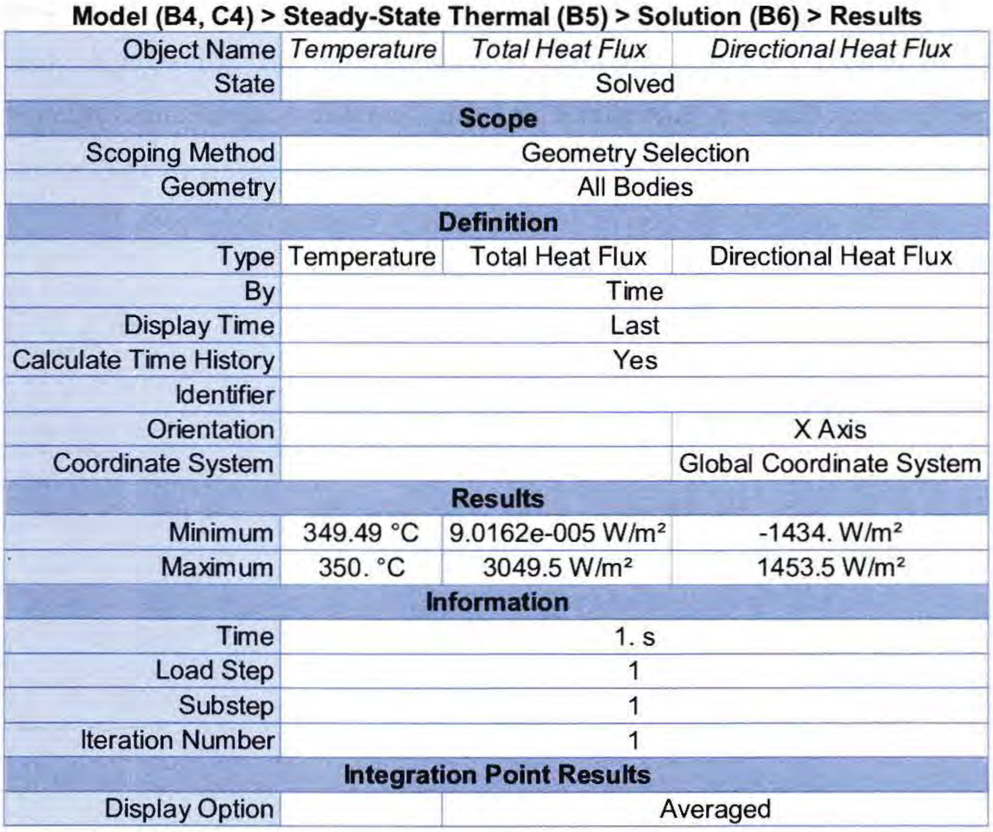
After considerations and calculations done in this project, the final values for the lightweight clutch disc are as follow:

i. Material used for the friction facing is a carbon-carbon composite
ii. Value of maximum temperature = 350 °C
iii. Value of minimum temperature = 349.49 °C
iv. Value of total heat flux = 3049.65 W/m^2

Formula that used to determine the total heat flux of carbon-carbon composite clutch disc and used to compare with the analysis value done by ANSYS software are as follow:

i. $Q = K * A * (\Delta T)$

After that, we used the ANSYS software for do the finite element analysis (steady state thermal analysis) on the design of the clutch disc. From the analysis, we get the value of temperature and the total heat flux when the temperature and convection is applied at the clutch disc. Table below show all the value:



Model (B4, C4) > Steady-State Thermal (B5) > Solution (B6) > Results

Object Name	*Temperature*	*Total Heat Flux*	*Directional Heat Flux*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Temperature	Total Heat Flux	Directional Heat Flux
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Orientation			X Axis
Coordinate System			Global Coordinate System
Results			
Minimum	349.49 °C	9.0162e-005 W/m²	-1434. W/m²
Maximum	350. °C	3049.5 W/m²	1453.5 W/m²
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	

Table 3 : Result of steady state thermal analysis

The parameter of total heat flux that obtain from the analysis is below than theoretical. So, the clutch disc that we designed is safe to use in the industrial application in term of safety and better than the commercial clutch disc. The clutch disc also can fabricated in future to use in automotive industrial. So, all the objective of the project is achieved.

5.2 RECOMMENDATION

After done design and analysis of the lightweight clutch disc, we can recomment that the clutch disc can be mix with other material that can make the clutch disc more safe and long lasting. The thickness of clutch facing can be adjust to know the effectiveness during engage with pressure plate. Beside that, dynamic analysis and static analysis for the clutch disc should be included in this project.

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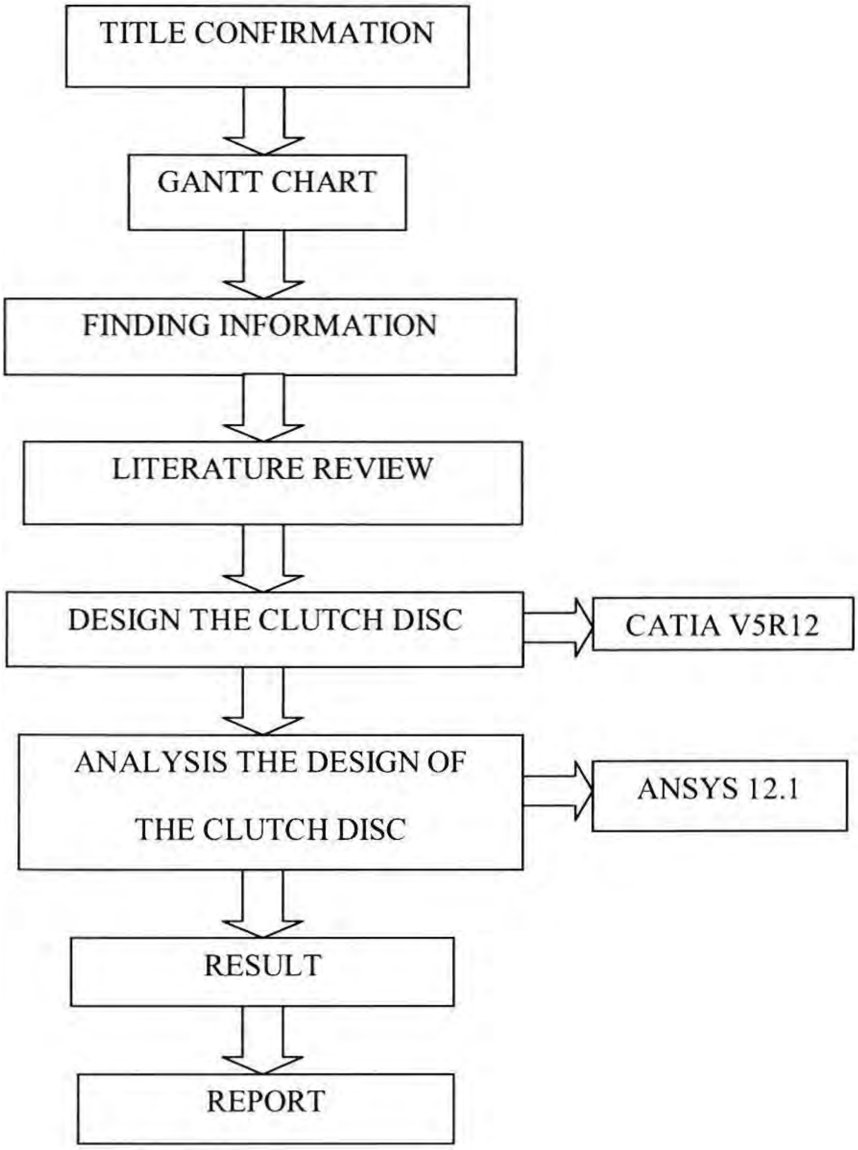
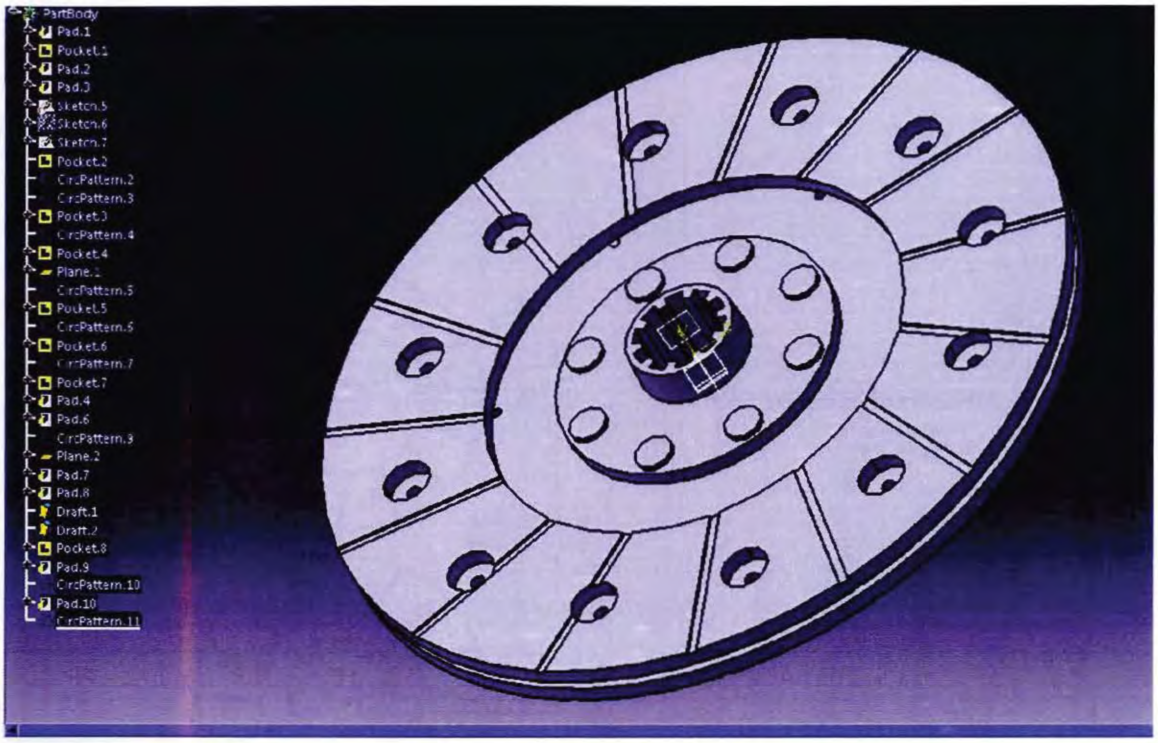
APPENDIXES

APPENDIX A: FLOW CHART



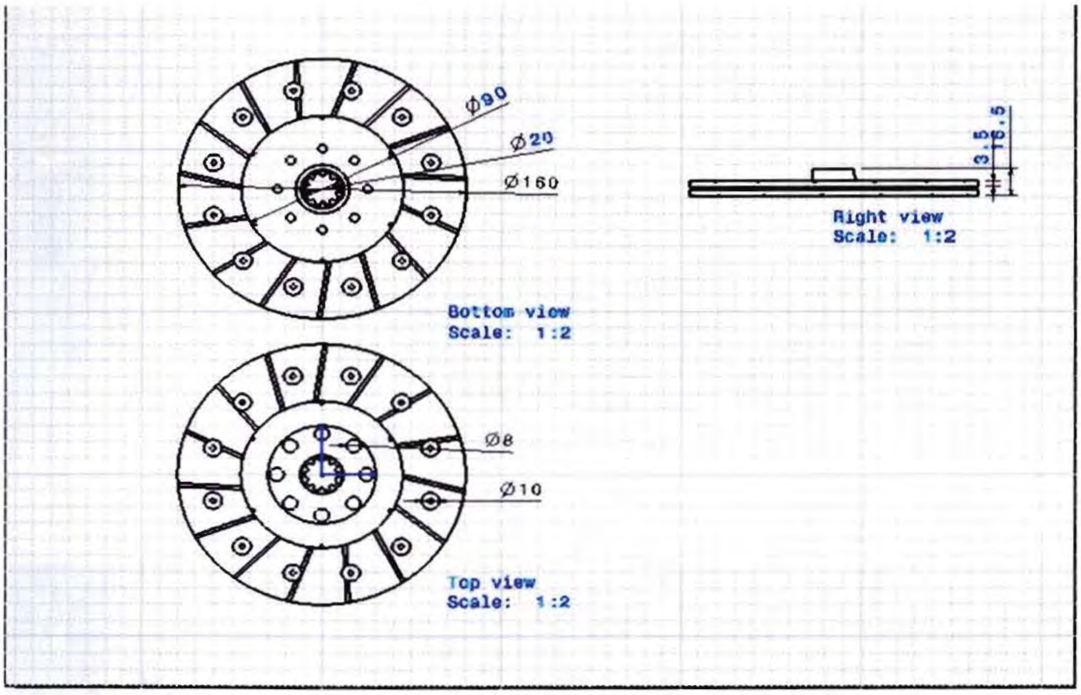
APPENDIX B

Clutch Disc (in CATIA V5)



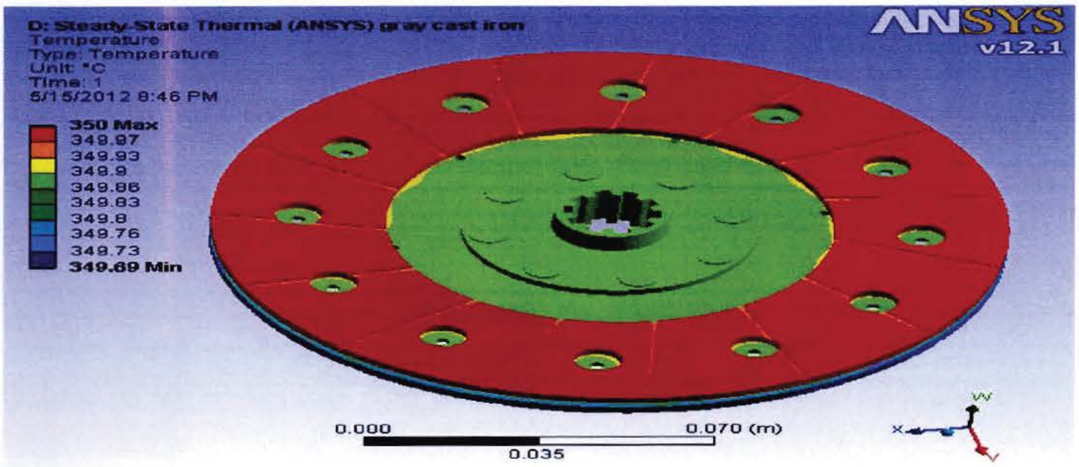
APPENDIX C

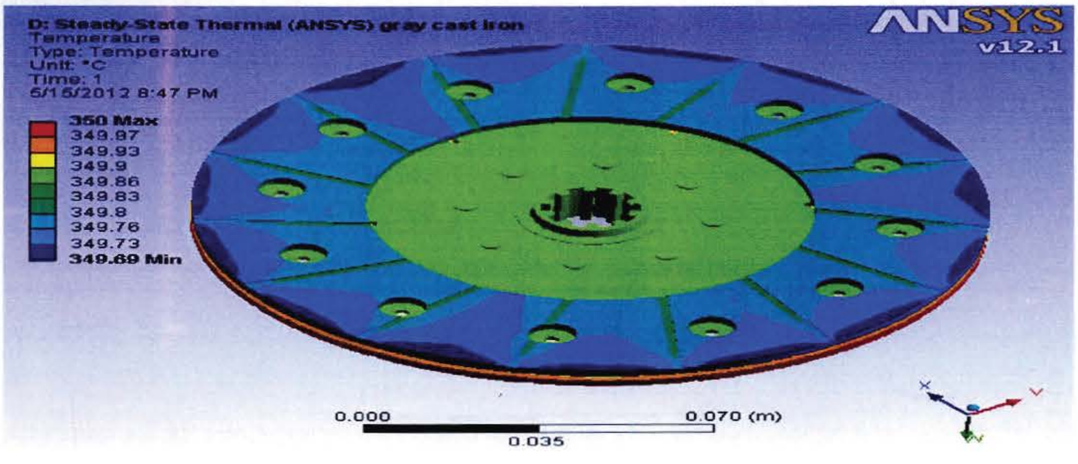
Isometric view of clutch disc



APPENDIX D

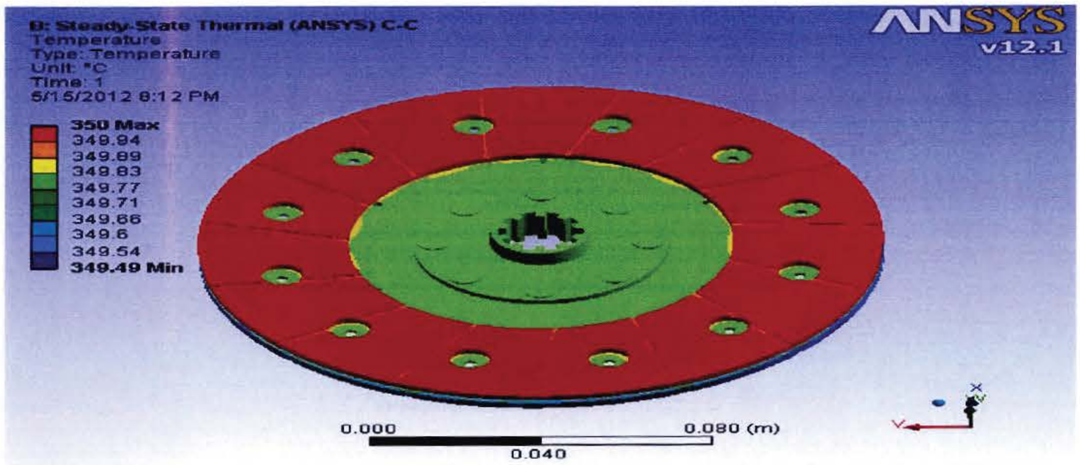
Gray cast iron – temperature

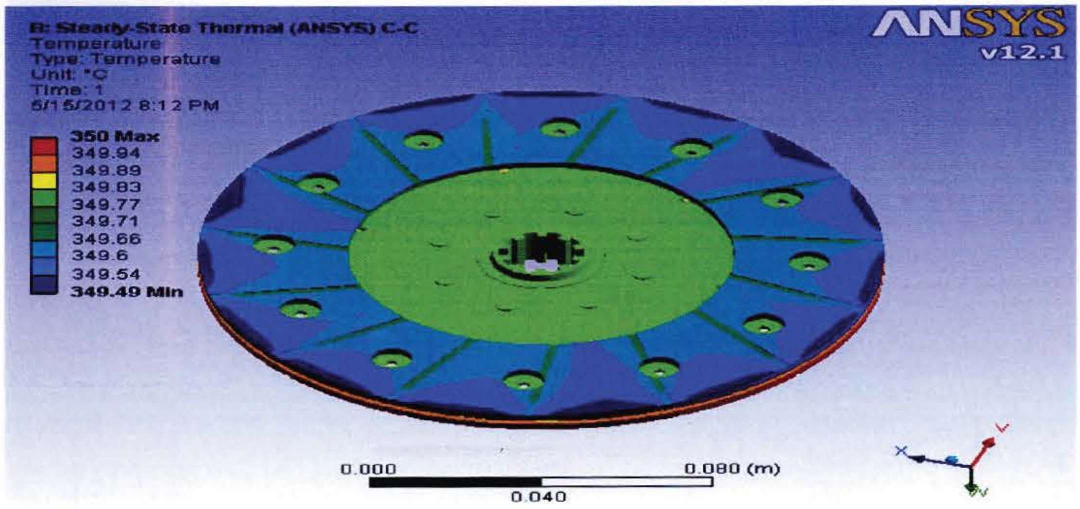




APPENDIX E

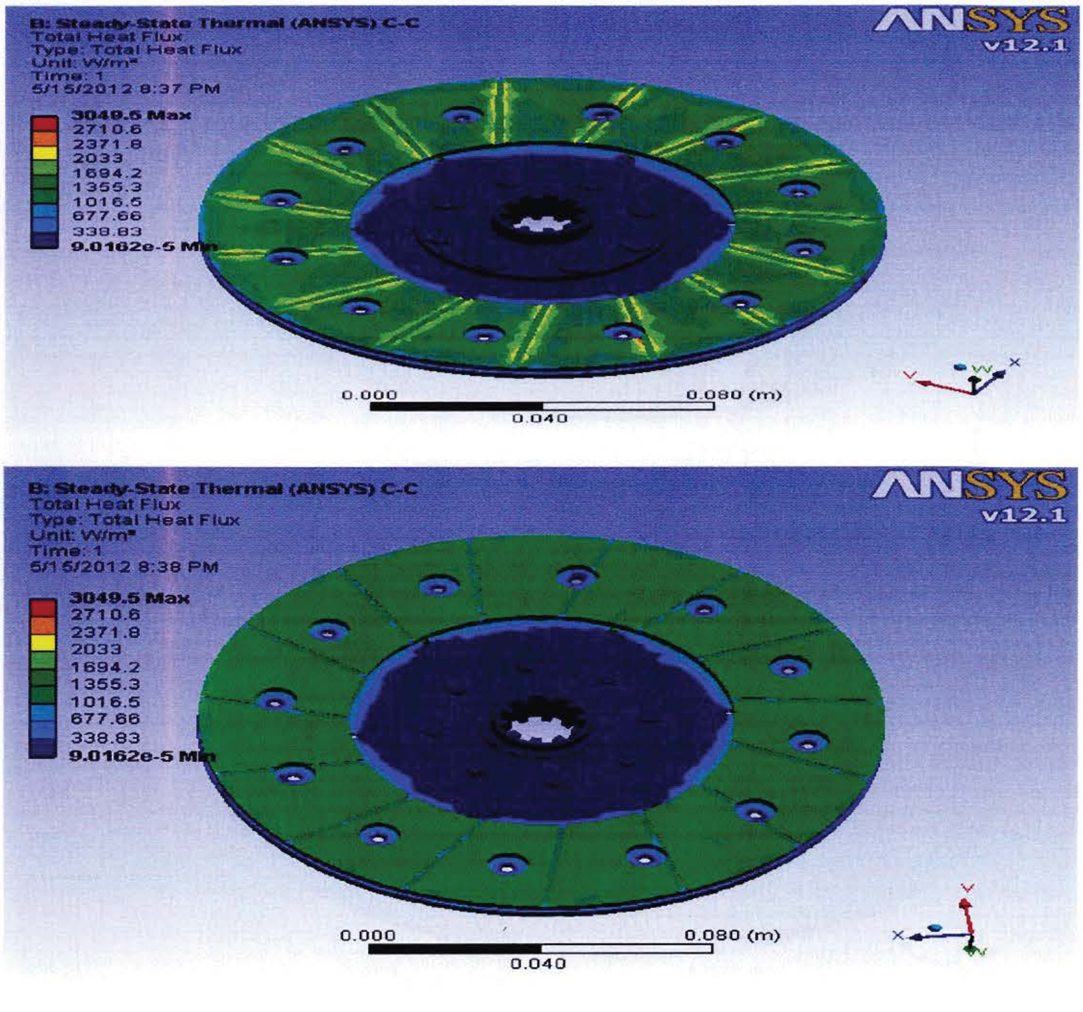
Carbon-carbon composite – temperature





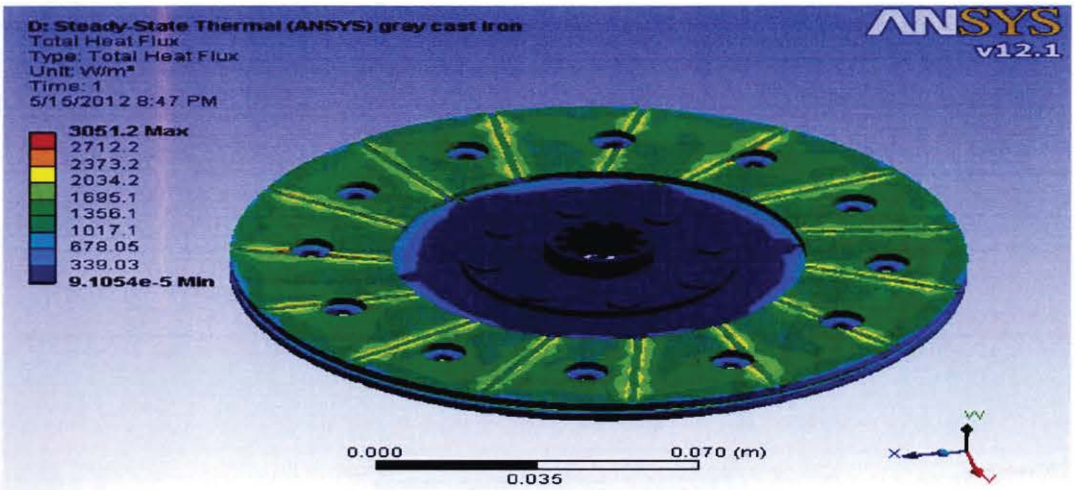
APPENDIX F

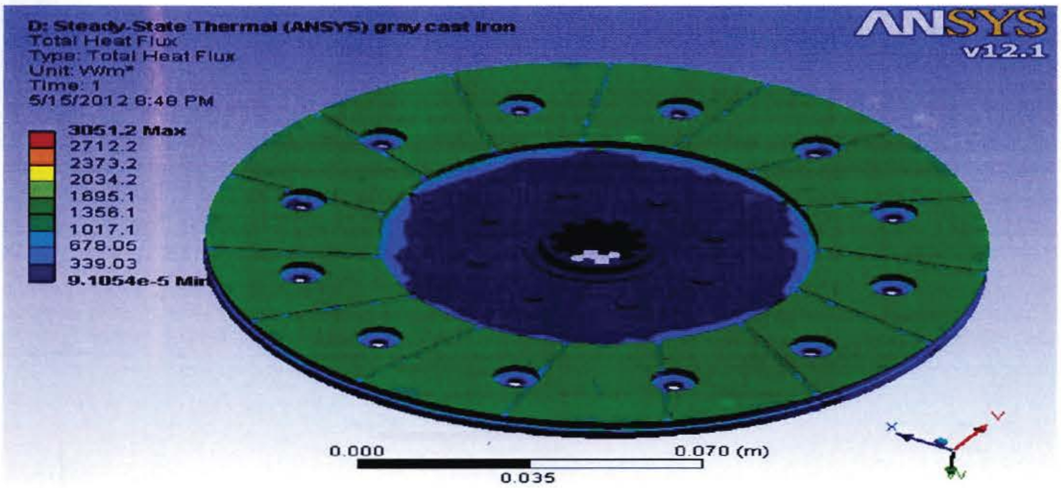
Carbon-carbon composite – total heat flux



APPENDIX G

Gray cast iron – total heat flux





APPENDIX H

Carbon-carbon composite – vector total heat flux