Addis Ababa University Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering

Optimization of brake disc thickness and radius using different disc brake materials by FEM

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Degree of Masters of Science in Rail way Mechanical Engineering

Submitted By: Aden Egueh Ali

Advisor: Mr. TSEGAYE FELEKE

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Approval of Board of Examining:

____________________	____________________	____________________
Name of Chair person,	Signature	Date
Tsegaye Feleke (Msc)		
____________________	____________________	____________________
Name of Advisor	Signature	Date
____________________	____________________	____________________
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DECLARATION

I, the undersigned, declare that this thesis entitled "Optimization of brake disc thickness and radius using different disc brake materials by FEM" is original work of mine and has not been presented for any degree in any university and all the sources of materials used for the thesis have been duly acknowledged.

Aden Egueh Ali	______________	______________
Name	Signature	Date

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ABSTRACT

The main purpose of this study is the optimization of disc brake materials by changing the radius and the thickness of the disc using different materials to choose the optimum disc brake material. The modelling of disc brake is made in CATIA software, the thermal and structure analysis is done using ANSYS workbench. In this research, a transient thermal and structural analysis was carried out to investigate the temperature variation across the disc and the total heat flux using ANSYS software. The thermal-structural analysis is then used to determine the deformation established and stresses in the disc. In all cases when the dimensions of disc model increase temperature, deformation and equivalent stress decrease. For example the deformation of cast iron decreases 7.0616e-5m to 5.4009e-5m when we change the model.

For the side of the material by varying the properties of the materials, the better material for this study is the aluminium alloys 7075 with silicon carbide SiC/AL7075 because it has the minimum deformation 3.6367e-5 for model3. Finally this thesis suggests the SiC/AL7075 to be used disc brake material for the future with the model3.

Keywords: Disc brake, cast iron, composite materials, dimension, ANSYS software, CATIA software.

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NOMENCLATURE

K_x= thermal conductivity in x-direction

K_y = thermal conductivity in y-direction

K_z= thermal conductivity in z-direction

C_p= specific heat

ρ = specific mass

Q= internal heat generation rate per unit volume

T = temperature that varies with the coordinates as well as the time

h=convective surface heat transfer coefficient.

T_1 = specified surface temperature

q_s=specified surface heat flux

T_s = unknown surface temperature

T_∞ =convective exchange temperature

ε=material"s emissivity

σ= Stefan-Boltzmann constant

m= masse of the vehicle

k = correction factor of rotating parts

K_d= proportion of heat entering the brake disc

S_b= braking distance of the vehicle

F_T =Tractive force

F_D= Drag force

F_R= rolling resistance force

F_G = Total weight component in the direction of the inclined plane

a_T = Train acceleration

a= deceleration of the train

P_B = braking power

ω = Angular velocity

R_W= wheel of radius

α = Gradient angle of the track

g = acceleration due to the gravity

t_b = braking time

A_d = contact swept area

r_{op}= outer pad radius

r_{ip}= inner pad radius

R_e =Reynolds number
P_r =Prandtl number
K_a =thermal conductivity

μ_{va}=dynamic viscosity
C_{pa}= specific heat capacity
P= pressure
F = force of rotor

M 1.1 = Model1 and material 1

M 2.2 = Model1 and material 2

M 3.3 = Model1 and material 3

CHAPER ONE

1. Introduction

1.1. Background

Rail or train transportation is one of important and economical transportation systems available. In rail transportation, a series of vehicles are run by means of wheels and guided track to carry passengers or freight stock from one place to another. A series of vehicles are pulled by single or multiple locomotives. Locomotives are powered by steam or diesel engines or through electricity. Depending on type of vehicles carried by a train, they classified as passenger and freight trains. Travelling speed is an important parameter in passenger trains whereas maximum tonnage carried is crucial for freight carriers. Brakes are used in trains for deceleration or to maintain constant speed while travelling downhill. In trains, brakes can be applied through mechanical loading or electrical systems or via a combination of both.

Tread or block braking is popular and frequently used mechanical braking system in trains.

In tread braking; friction material is pressed against tread region of a railway wheel to reduce speed or for bringing train to rest. Tread braking is famous for its simple mechanism and operation. Cast-iron and polymer composites are important friction materials used for braking of trains.

Railway in Ethiopia was a firm founded in 1894 to build and operate a railway across eastern Ethiopian from the port of Djibouti to the capital of Addis Ababa. It was founded by Alfred Ilg and Leon Chefneux and headquartered in Paris, France. The firm failed in 1906 when political discord halted construction, and it failed to obtain any new capital. The portion it had completed ran from Djibouti to just short of Harare, the principal entrepôt for existing commerce in southern Ethiopia. Its terminus evolved into the city of Dire-Dawa, today a larger city than Harare itself. Discussion of an Ethiopian railway was initiated by Alfred Ilg, an advisor to Emperor Menelek II. He had attempted to interest the previous emperor and other Ethiopian political figures in the construction of a railway to replace the six-week mule trek between the capital and the French port city, but had no success. When Menelek II acceded to the throne in 1889, negotiations began a new and a decree was granted on February 11, 1893, to study the construction of rail line. Ilg, a Swiss citizen, and a number of French associates put together a firm and received a royal charter on March 9, 1894, enabling them to start work.

The demands and threats of the two governments led Emperor Menelek in 1902 to forbid the expansion of the railway line to Harare.

Ethio-Djibouti Railways also known as the **Ethio-Djibouti Railway Enterprise**, is a railway company based in the Horn of Africa. It was established in 1981 as the successor to the **Franco-Ethiopian Railway**, and it is jointly owned by the governments of Ethiopia and Djibouti.

The railway links Addis Ababa, the capital of landlocked Ethiopia, to the Port of Djibouti in Djibouti City. Maintenance shops along the line are located in Dire-Dawa, which grew up as the railway depot for nearby Harar.

The railroad is currently abandoned between Addis Ababa and Dire-Dawa. Through trains have not run since 2008, Service is available between Dire Dawa and Djibouti. The parallel Addis Ababa–Djibouti Railway, an electrified standard gauge railway, began freight operations in October 2016. It was built and is operated by Chinese state-owned companies.

The **Addis Ababa–Djibouti Railway** is a standard gauge railway that links Addis Ababa with the port of Djibouti, providing landlocked Ethiopia with railroad access to the sea. More than 95% of Ethiopia's trade passes through Djibouti, accounting for 70% of the activity at the port of Djibouti.

The railway was built between 2011 and 2016 by the China Railway Group and the China Civil Engineering Construction Corporation. Financing for the new line was provided by the Exim Bank of China, the China Development Bank, and the Industrial and Commercial Bank of China. A total of US$4 billion dollars were invested into the railway.

Trial service began in October 2016, and regular services are expected to begin in 2017. The standard-gauge railway replaces the abandoned Ethio-Djibouti Railway, a meter gauge railway that was originally built by the French between 1894 and 1917

For most of its length, the railway runs parallel to the abandoned meter-gauge Ethio-Djibouti Railway However, the standard-gauge railway is built on a new, straighter right-of-way that allows for much higher speeds. New stations have been built outside of city centers, and the old stations have been abandoned.

The line is double-track for the first 115 km from Sebeta to Adama, and single-track from Adama to the sea. The railway begins in Sebeta, just outside of the Ethiopian capital city of Addis Ababa. Briefly entering the city of Addis Ababa to serve the main station, the line then skirts Mount Furi in a wide curve before turning east. At Bishoftu, it crosses over the Addis Ababa–Adama Expressway for the first time. The line then runs southeast alongside the expressway until reaching Adama, where it turns northeast towards Dire Dawa.

At Awash, there is a junction with the Mek'ele–Awash Railway, which is still under construction as of 2016. After passing Dire Dawa, the railway heads directly for Djibouti. Crossing the border between Dewele and Ali Sabieh, it reaches the Djibouti passenger terminal at Nagad, near Djibouti–Ambouli International Airport. Freight trains continue to the Port of Doraleh on diesel power.

As the Ethio-Djibouti Railway deteriorated from lack of maintenance, Ethiopia lost railroad access to the sea. The existing meter gauge railway had been originally built by the French between 1894 and 1917 and had all the deficiencies of a colonial-era railway, with steep gradients and tight curvatures. Since China was financing the construction of a standard gauge railway network in East Africa, Ethiopia and Djibouti chose to abandon the meter-gauge railway and build a new standard gauge link.

In 2011, the Ethiopian Railway Corporation awarded contracts to two Chinese state-owned companies for the construction of a new standard gauge railway from Addis Ababa to the Djibouti border. The 320 km stretch from Sebeta to Mieso was awarded to the China Railway Group, and the 339 km section from Mieso to the Djibouti border was awarded to the China Civil Engineering Construction Corporation. In 2012, Djibouti selected the China Civil Engineering Construction Corporation to complete the final 100 km to the port of Djibouti.

In 2013, loans totaling $3 billion were secured from the Exim Bank of China, with $2.4 billion going to the Ethiopian section of the railway and the balance to be spent in Djibouti. The total costs of the railway amounted to $1.873 billion for the Sebeta-Mieso section, $1.12 billion for the Mieso-Dewele section and $525 million for the Dewele-Doraleh section.

20,000 Ethiopians and 5,000 Djiboutians were hired for construction work. Track-laying was completed on the Mieso-Djibouti segment of the project in June 2015. Although construction was still in progress on other sections, the completed portion of the railway was put into emergency operation in November 2015 to carry grain to drought-stricken Ethiopia. Farmers in Ethiopia had suffered crop failures of 50-90%, and the port of Djibouti backed up with ships waiting to unload grain.

The completed railway was formally inaugurated on 5 October 2016 by the presidents of Ethiopia and Djibouti. The two prime contractors have formed a consortium to operate the railway for the first 3–5 years, while local personnel are trained [1].

1.2. Braking Systems in Railway Vehicles

The brakes are used on the coaches of railway trains to enable deceleration, control acceleration (downhill) or to keep them standing when parked. While the basic principle is similar from road vehicle, the usage and operational features are more complex because of the need to control multiple linked carriages and to be effective on vehicles left without a prime mover. In the control of any braking system the important factors that govern braking action in any vehicle are pressure, surface area in contact, amount of heat generation and braking material used. Keeping in view the safety of human life and physical resources the basic requirements of brake are:

- The brake must be strong enough to stop the vehicle during an emergency with in shortest possible distance.
- There should be no skidding during brake application and driver must have proper control over the vehicle during emergency.
- Effectiveness of brakes should remain constant even on prolonged application or during descending on a down gradient
- Brake must keep the vehicle in a stationary position even when the driver is not present.

The brake used in railway vehicles can be classified according to the method of their activation into following categories.

- Pneumatic Brake
- Electro-dynamic Brake
- Mechanical Brake
- Electromagnetic Brake

Pneumatic Brake may be further classified into two types

- Vacuum Brake
- Compressed air brake

1.2.1. Vacuum brake & its limitations

The vacuum brake system derives its brake force from the atmospheric pressure acting on the lower side of the piston in the vacuum brake cylinder while a vacuum is maintained above the piston. The train pipe runs throughout the length of the coach and connected with consecutive coaches by hose coupling. The vacuum is created in the train pipe and the vacuum cylinder by the ejector or exhauster mounted on the locomotive.

Vacuum brake system has following limitations:

- Brake cylinder piston takes longer time to release after each application of brakes because of single train pipe. On a very long train, a considerable volume of air has to be admitted to the train pipe to make a full brake application, and a considerable volume has to be exhausted to release the brake.
- Vacuum brakes are not suitable for high speed trains the maximum pressure available for brake application is only atmospheric. The brake power is inadequate for higher loads and speed.
- The practical limit on the degree of vacuum attainable means that a very large brake piston and cylinder is required to generate the force necessary on the brake blocks.

1.2.2. Electrodynamics braking system

Braking system used is electric trains is electro-dynamic braking that converts the motor into a braking generator dissipating the kinetic energy in the form of heat. Regenerative braking uses the generated electricity instead of dissipating it as heat, and is becoming more common due to its ability to save energy. Principle of the dynamic braking and regenerative braking systems is shown in figure bellow.

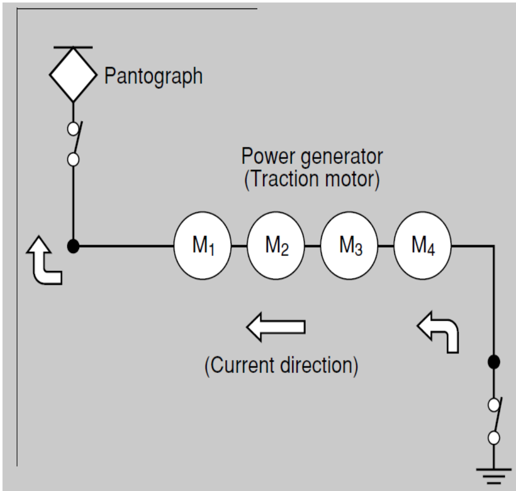


Figure1.1 Principle of regenerative braking

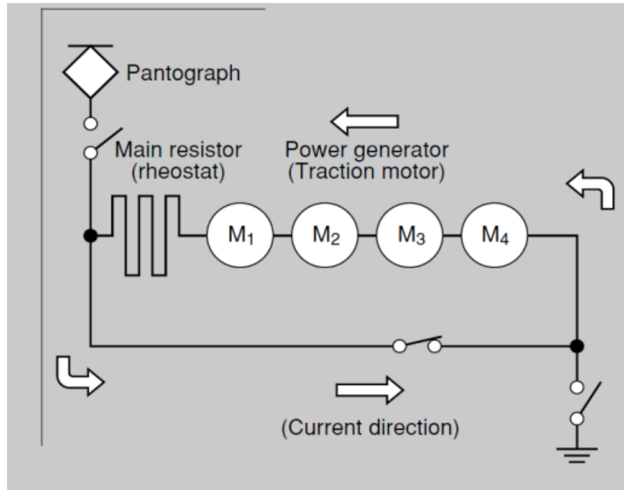
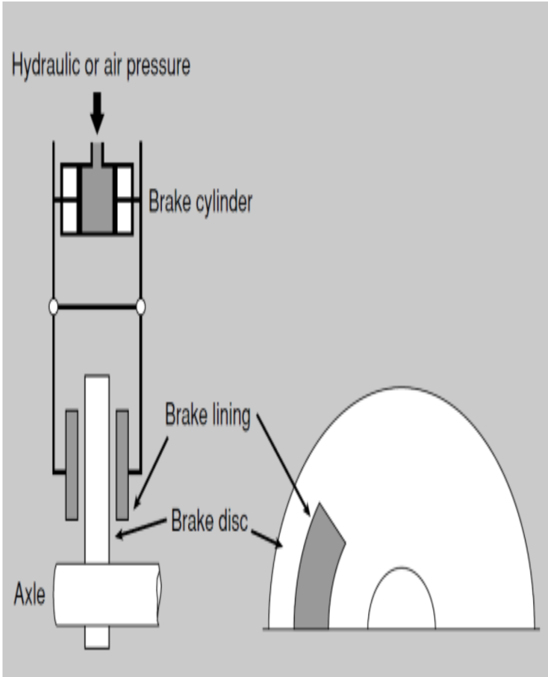


figure 1.2 Principle of dynamic braking

1.2.3. Mechanical braking system

The basic braking devices used by mechanical braking systems are: wheel treads brakes axle-mounted disc brakes and wheel-mounted disc brakes. These brake mechanisms use a brake shoe that applies friction force to the disc. The applied pressure is adjusted to control the braking force. In wheel-tread brake, the brake shoe applies friction force to the wheel tread, creating a sliding effect. High-speed trains cannot use this type of brake, because doing so may damage the wheel tread. Therefore, they use axle- or wheel-mounted disc brakes.

Axle-mounted disc brakes require sufficient space to accommodate therefore used in trailer bogies. Wheel mounted disc brakes are used on motor bogies because it requires accommodating the traction motor only and having insufficient space for an axle-mounted brake. In both systems, compressed air or oil is applied to a brake cylinder that pushes the brake lining against the disc. Brake discs are dead weight that is useful only during braking. Therefore operators can install lighter discs. Carbon/carbon- composite multi-discs and aluminium composite discs offer lighter weights and are widely used. The carbon/carbon-composite multi-disc has alternate sections of carbon-fiber rotors and stators. During braking, they rub against each other to create a frictional force that slows down the wheel or axle. The disc is lighter in weight than conventional materials and has good heat-resistant properties. Aluminium composite brake discs may be made much lighter than today's forged steel and cast-iron brake discs. Moreover their structure is common for both axle- or wheel-mounted discs, achieving a much lighter disc without design [2]



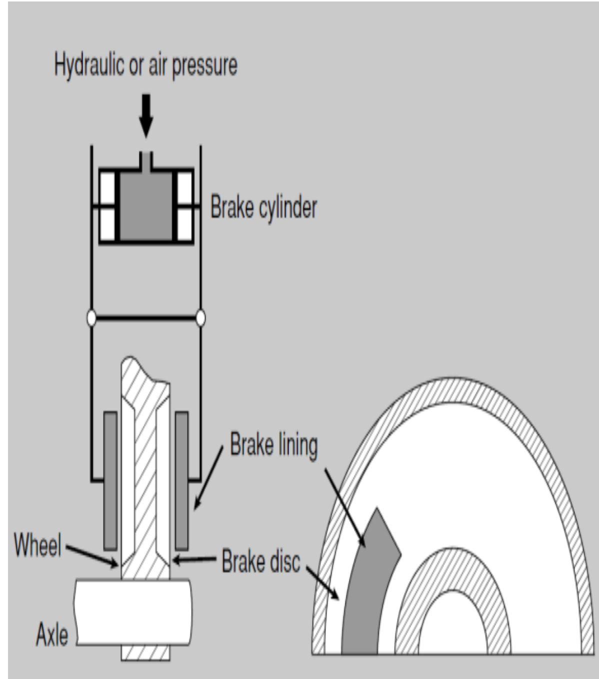


Figure 2.1 Principle of axle-mounted disc brake **Figure 2.2** Principle of wheel-mounted disc brakes

1.3. Disc brake materials available

Cast Iron

Cast iron is normally used for making the brake disc. The excellent heat absorbing capacity, low cost, simple manufacturing methods are the reasons for using the cast iron in these applications. Low corrosion resistance, rusting, brake noise, and high density are the disadvantages of using this material for brake applications. Since the brake rotors represent rotating weights, increase in their mass will also increase the inertia of the rotating parts and can also decrease vehicle dynamics and acceleration.

Types of cast iron

White cast iron

When the white cast iron is fractured, white coloured cracks are seen throughout because of the presence of carbide impurities. White cast iron is hard but brittle. It has lower silicon content and low melting point. The carbon present in the white cast iron precipitates and forms large particles that increase the hardness of the cast iron. It is abrasive resistant as well as cost-effective making them useful in various applications like lifter bars and shell liners in grinding mills, wear surfaces of pumps, balls and rings of coal pulverisers, etc.

Grey cast iron

Grey is the most versatile and widely used cast iron. The presence of carbon leads to formation of graphite flakes that does not allow cracks to pass through, when the material breaks. Instead, as the material breaks the graphite initiates numerous new cracks. The fractured cast iron is greyish in colour, which also gives it the name. The graphite flakes make the grey cast iron exhibit low shock resistance. They also lack elasticity and have low tensile strength.

However, the graphite fakes gives the cast iron excellent machinability, damping features as well as good lubricating properties making them useful in many industrial applications. The graphite microstructure of the cast iron has a matrix that consists of ferrite, pearlite or a combination of two. The molten grey iron has greater fluidity and they expand well during the solidification or freezing of cast iron. This has made them useful in industries like agriculture, automobile, textile mills, etc.

Ductile cast iron

Ductile cast iron is yet another type of ferrous alloy that is used as an engineering material in many applications. To produce ductile iron, small amount of magnesium is added to the molten iron, which alters the graphite structure that is formed. The magnesium reacts with oxygen and sulphur in the molten iron leading to nodule shaped graphite that has earned them the namenodular cast iron. Like malleable iron, ductile iron is flexible and exhibits a linear stress strain relation. It can be casted in varied sizes and into varying thickness [3].

Materials composites

Nowadays with the modern development need of developments of advanced engineering materials for various engineering applications goes on increasing. To meet such demands metal matrix composite is one of reliable source. Composite material is one of the reliable solutions for such requirement. In composites, materials are combined in such a way as to enable us to make better use of their parent material while minimizing to some extent the effects of their deficiencies. The simple term 'composites' gives indication of the combinations of two or more material in order to improve the properties.

The combined effect of reinforcements on **Aluminium Metal Matrix composites** with individual and multiple particulate reinforcements like Hybrid Metal matrix composites or silicon carbide are finding increased applications in aerospace, automobile, space, underwater, and transportation applications. This is mainly due to improved mechanical and tribological properties like strength, stiffness, abrasion, impact resistance and wears resistance.

There are a lot of Aluminium alloys with different percentage composition of Magnesium (Mg), Silicon (Si), Iron (Fe), Copper (Cu), Titanium (Ti), Manganese (Mn), Zinc (Zn) and also they different the designation of aluminium alloys and heat treatment solution. There is different series of aluminium alloys (1xxx, 2xxx, 3xxx, 4xxx, 5xxx, 6xxx, 7xxx…)

High strength aluminum alloy AA7075 (Al-Zn-Mg-Cu) is a precipitate hardenable alloy widely used in the aerospace, defense, marine and automobile industries. Use of the heat treatable aluminum alloys in all these sectors is ever-increasing owing to their excellent strength-to weight ratio and reasonably good corrosion resistance [4].

Metal matrix composites are widely used in components of various components of industrial equipment because of their superior material properties like high stiffness to weight ratio and high impact strength and fracture toughness while compared to the conventional material. Due to the concepts of high strength to low weight ratio, Al 7075 was extensively applied in aircraft engine and wings. Even if Al 7075 has higher hardness, higher strength, excellent wear resistance, and high-temperature corrosion protection, it is in need of further enhancement of properties for increasing its applicability. This paper presents the mechanical behavior of aluminium 7075 reinforced with Silicon Carbide (SiC) and Titanium Carbide (TiC) through powder metallurgy route. These specimens were produced by powder metallurgy method. The hybrid composite was made by Al 7075 alloy as the matrix with Silicon Carbide and Titanium Carbide as reinforcement. Silicon Carbide and Titanium Carbide are mixed in different weight ratio based on the design matrix formulated through a statistical tool, namely, Response Surface Methodology (RSM). Enhanced mechanical properties have been obtained with 90% of Al 7075, 4% of TiC, and 8% of SiC composition in the composite. Coefficient of friction appears to be more which has been determined by ring compression test [5].

Carbon-carbon composites

One of the most advanced and promising engineering material is the carbon fiber reinforced carbon-matrix composite, often termed a carbon–carbon composite; as the name implies, both reinforcement and matrix are carbon. These materials are relatively new and expensive. Their desirable properties include high-tensile module and tensile strength that are retained to temperatures in excess of 20000C (3630oF), resistance to creep and relatively large fracture toughness values. Furthermore, carbon-carbon composites have low coefficient of thermal expansion and relatively high thermal conductivities; these characteristics, coupled with high strengths, give rise to a relatively low susceptibility to thermal shock. Their major drawback is a propensity to high-temperature oxidation. The carbon–carbon composites are employed in rocket motors, as friction materials in aircraft and high-performance automobiles, for hot pressing molds in components for advanced turbine engines and as ablative shields for re-entry vehicles [6].

1.4. Problem statement

Most of railway vehicles are using disc brakes for braking. The main problem of braking of heavy railway vehicle is the great input of heat flux into the disc when braking is applied. Because of the high heat flux, the temperature will be generated and the brake disc material is exposed to high stress and deformation

The friction forces generated during braking between brake pads and discs produce high thermal gradients on the rubbing surfaces. These thermal gradients may cause braking problems such as brake fade, premature wear etc...

The material of disc brake used in AALRT is cast iron which, low corrosion resistance, rusting, brake noise, and high density, are the disadvantages of using this material for brake applications. The composite materials have better mechanical and tribological property such as aluminum alloy and carbon-carbon.

In the last few years there is a lot of research on the composite materials in different sector industrial such as the car body, brakes, etc.. So we need to develop new brake materials for high energy braking conditions with higher frictional performance and when braking is applied the disc brake and pad are under the high temperature and high braking pressure condition. So we need to develop new materials with less weight and high thermo-mechanical stress values.

1.5. Objectives

1.5.1. General Objective

The main objective of this study is to analyse alternate materials and dimension to be used for AALRT disc brake with analytical method. So this paper does the comparison of thermo-mechanical property and for different dimension of the materials used for disc brake like aluminum alloy with silicon carbide SiC/AL705, carbon-carbon composite and cast iron.

1.5.2. Specific objective:

The specific objectives of this research include:

- Select the materials which are concerned of this study
- Compare those materials for their thermo-mechanical property such as stress, maximum temperature, deformation etc...With the existing disc brake materials for AALRT.
- Analyse for these materials for different radius and thickness.
- Modeling the disc brake based on ERC data and by changing the thickness and radius of the disc brake with CATIA software and analysis with ANSYS 17.2 workbench.

1.5.3. Scope of the study

The scope of this research will cover:

- Thermo-mechanical analysis of the disc brake is presented
- Constructs 3D model of disc brake using CATIA software using ERC train disc brake dimensions.
- Perform thermo-mechanical analysis for the 3D modelling using ANSYS 17.2 for showing the temperature distribution on disc brake and comparing its value on the different materials composite and dimension.
- Finally concludes with a summary of the contributions. Following that, the direction of further studies required to continue this research is highlighted.

1.5.4. Limitation of study

Some of the limitations of this study are mentioned as follows:

- Experimental thermo-mechanical analysis will not be performed in this study due to the absence of laboratory and tools used to perform the property of materials.
- Experimental design of these different materials for disc brake will not be possible because lack of laboratory materials.

1.6. Methodology

The methodology used for this study is analytic using finite element method based on the ANSYS software because there was a lot of researchers already used this software and they got better results. This software shows a different colors for the heat generate and the temperature rise to easily understand. The disc brake will be designed with CATIA software.

1.6.1. Type of investigation

The type of this study is analytical research because it uses the already available data or information, and analyzes them to make comparison for different materials and dimension of disc brake and suggest the optimum material and model.

1.6.2. Data collection

For the purpose of this research, and in order to achieve the general objectives of this report of the research the data will be collected through secondary data collection method:

- By browsing different published papers and journals
- By visiting to the Addis Ababa LRT manufacturing work shop found on Leghar
- From the information that we have learned in class i.e. lecture notes.

CHAPER TWO

2.1. Literature review

S. Dhiyaneswaran, Dr. K. S. Amirthagadeswaran [7] Cast iron disc brakes are commonly used, since its heavy weight results in high fuel consumption. So weight reduction in disc brake is needed. Aluminium metal matrix composites particulate with 20% silicon carbide provides appreciable weight reduction with improved wear resistance, hardness and thermal conductivity. In this study an attempt has been made to replace disc brake material from Cast iron to Aluminium silicon carbide composite. The modelling and analysis have been done using finite element analysis software. A model of disc brake was created virtually and this model tested with conventional and proposed material. The observations and inferences are presented. Comparison of stress distribution, equivalent elastic strain, displacement and strain energy for conventional and proposed material indicates that Aluminium silicon carbide composite satisfies the requirement for disc brake application. It is concluded that Aluminium silicon carbide composite can be used in automotive to replace the conventional material for improved vehicle performance.

Yathish K.O, Arun L.R, Kuldeep B, Muthanna K.P [8] In automotive field lots of studies are going on to conventional materials with the composites. Hence to reduce weight, Aluminium based metal matrix composite (MMC) found to be the best alternative for this. The motive of this study was to analyze the performance of disc brake for different materials (Cast iron & Aluminium6061-SiC-redmud composite) under same working conditions/parameters. And the material impact on displacement, stress, contact pressure, contact status, contact sliding distance of disc and pad assembly are obtained using software packages like ANSYS. From this paper they get these results:

- The stress developed in the disc brake is comparatively less in the Aluminium6061-SiC compared to the former (Cast iron).
- The displacement reduces with the change of material aluminium6061-SiC.
- Contact sliding, contact pressure decreases with the material change (Aluminium6061-SiC).
- Contact status will be more in the Aluminium6061-SiC.

M.Palanivendhan, Yash Nigam, Kshitij Trivedi [9] Composite materials have proved themselves as ideal materials for automobile and aerospace sectors due to their enhanced mechanical properties than conventional materials. Aluminium alloy based metal matrix composites (MMC) plays a vital role in above mentioned fields of engineering as they consists of high specific strength, more thermal stability and wear resistance. In this project, the fabrication of Aluminium Silicon Carbide is done by stir casting method and the composition of SiC is varied by 10%, 20% and 30% in the specimens. The resultant composite material is tested for their hardness, impact, tensile, and wear resistance. A composite material provides enhanced physical and chemical properties when compared to conventional alloys for various applications. They are gaining high popularity in the automobile and aerospace industries as their properties can be altered according to the need. Aluminium composites offer excellent thermal conductivity, high strength, excellent abrasion resistance, high temperature operation and they can be fabricated and get their properties altered using conventional equipment.

The fabrication of Aluminum SiC composite by stir casting methods lead to the following results:

a. Addition of silicon carbide in proportionate ratios to aluminum showed that the hardness of the aluminum was increased due to strengthening of the covalent bonds, which thus helped in increase of tensile strength

b. The impact strength of the material was reduced.

c. The wear resistance was increased with increase percentage of SiC in the composite thus making it suitable for prolonged use.

Aluminium alloy 7075 is an aluminium alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability.

7000 series alloys such as 7075 are often used in transport applications, including marine, automotive and aviation, due to their high strength-to-density ratio. Their strength and light weight is also desirable in other fields.

In recent years, the developments of metal matrix composite (MMCs) have been receiving worldwide attention on account of their superior strength and stiffness. They also have high wear resistance and creep resistance in comparison to their corresponding wrought alloys.

In this work, MMC having 7075Aluminium alloy (AA7075) as matrix and silicon carbide (SiC) as reinforcement, has been identified, since it has potential applications in aircraft and automobiles industries because of lower weight to strength ratio, high wear resistance and creep resistance. Stir casting has been identified as process to fabricate the particulate metal matrix composite (PMMC) [10].

Pruthviraj R. D. [11] The Silicon Carbide content in Aluminum 7075 alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of Silicon Carbide will be advantageous to reduce the density and increase in the strength of the alloy, but the corrosion resistance is thereby significantly increased.

Liang Yu, Yanli Jiang, Senkai Lu, Hongqiang Ru, and Ming FANG [12]

In today's automobile and motorcycle industry, brake disc is known to be the most effective deceleration device and also known to be the most popular method used. While braking, most of the kinetic energy is converted into thermal energy and this increases the disc temperature.

A high temperature in the disc will lead to the problem of disc warping and will cause an undesirable effect on vehicle handling. The iron brake disks are used in the China Railway High speed 3(CRH3). In particular, brake disks made of aluminum alloys are more preferred because of the weight and the cost effectiveness. Therefore, a reliable design is required to guarantee the service strength under operational conditions and full functioning of the brake disks. According to the experimental results of MINDIVAN et al, among the composites reinforced by SiC particle with 2618, 6082, 7012 and 7075 matrix, the wear resistance of SiC/7075 is the best.

Yu Shu, Chen Jie, Huang Qizhong, Xiong Xiang, Chang Tong1 and Li Yunping [13]

This paper describes the tribological properties of carbon/carbon composites used as braking materials under various braking speeds, in which the materials with three kinds of microstructures were used: rough lamina (sample A), smooth lamina (sample B), and the mixture of rough lamina and smooth lamina (sample C), respectively. Friction tests were carried out through a laboratory dynamometer. Polarized optical microscopy (OM) and scanning electron microscopy (SEM) were used to characterize the microstructure and worn surface. Results indicated that the friction coefficient of sample A reached a peak value at braking speed lower than that in both sample B and sample C. However, when the friction coefficients reached to the peak values the temperature inside the worn surface was observed to be approximately 250_C for all of the samples. The weight losses in all of the samples were observed to increase with increasing braking speed; however, the oxidation losses at speed of 28m.s-1 are higher than that of 30m.s-1 for all of the samples.

With the increasing braking speeds, the friction coefficient of (sample A) increased to the peak value at the speed of 15m.s-1, and then declined toward a stable value. The friction curves of sample B and C were similar: coefficient of friction is minimum at the speed of 15m.s-1 and increased to a peak value at the 20m.s-1, then decreased to a constant value. No matter what kinds of material, when ‘‘low-energy peak’’ appears, the temperatures under the friction surface 1mm are observed to be approximately 250’C. The weight loss of materials increased with the increasing braking speed, while the oxidation abrasion at 30m’s-1 are less than that of 28m.s-1 for all of the samples due to the low bond energy between the graphite layers and the hardness of wear debris at high temperature in the friction surface.

S.R. Dhakate, T. Aoki2, T. Ogasawara [14] High temperature tensile properties of 2D carbon-carbon composite made from high strength T700 carbon fibers were evaluated at different temperatures. Carbon-carbon composites were heat treated at different temperatures i.e., 750, 1000, 1500, 2000, 2500 °C and their tensile properties were measured at room temperature and at different high temperatures. It is observed that, maximum value of tensile strength at room temperature is of composite heat treated at 1500 °C thereafter strength decreases with increasing processing temperature up to 2500 °C. The decreases in strength are related to degradation of fiber properties in composites and in-situ damage. On the other hand, tensile strength is higher at high temperature compared to room temperature. It increases progressively with increasing the test temperature up to 2000 °C. Thereafter, strength decreases and ultimate value of tensile strength is less than that of the room temperature value of 2500 °C heat treated composites. Increase in strength up to 1500 °C is due to the improvement in fiber-matrix interactions, matrix properties due to relaxation of thermally induced stresses during high temperature test. Above 1500 °C enhancement in tensile strength is due to the enhancement in strength of carbon fibers and due to the creep deformation. Decrease in strength at measurement temperature 2500 °C is due to the additional in-situ degradation of fiber properties during high temperature test.

Saifeldein Arabab [15]. Carbon- Carbon (C-C) composites are a rare group of composite materials that continues to use its properties to the maximum temperatures, lightest weights, inertness, and high degree of toughness compared with other materials. These properties make Carbon- Carbon (C-C) composites perfect for the most advanced applications in the mechanical engineering fields. The disadvantages that limit the distribution and development of Carbon- Carbon (C-C) composites are fabrication processes use are extremely inefficient, and oxidation is fast in an atmosphere at temperature over 400Co. The cost of Carbon- Carbon (C-C) composite varies, but is well in excess. In military applications, high premiums are paid for improved performance rather than price. Carbon- Carbon (C-C) composites businesses predict increases in the next decade in materials usage. Carbon- Carbon (C-C) composites used in the commercial sectors as brakes, heat exchangers, and furnace elements are restricted by cost, unlike in military fields as rocket components, jet engine parts, and brakes. Carbon- Carbon (C-C) composites will remain the highest performance materials through the coming year.

Telang A K,Rehman A,Dixit G,Das S [16] Brake technology just like suspension & fuel system technology has come a long way in recent years. Automobile braking systems normally use brake discs of steel or grey cast iron, which are then paired with composite organic brake pads. These types of materials are suitable for use in braking systems with moderate loads, but vehicle manufacturers are tending to design increasing number of vehicles with more braking power. In addition, a history of high operating costs for on – highway vehicles and for aircrafts has encouraged designs for weight reduction with long service of braking systems. Redesigning of the braking system by substitution of lighter material like aluminium and carbon composite brakes primarily have been responsible for this state of the art technology, which is being used in aircrafts and formula one racing cars.

The requirement is of the materials that have light weight, are strong, abrasion resistant and are not corroded easily. Composite materials provide such unique combination of properties. In this review the alternate materials for automobile brake applications with special attention to aluminum composites have been done.

The properties of AMCs have been widely examined and would appear to offer several major advantages, namely-

• The friction coefficient of AMC is 25-

30% times that of cast Iron and better wear characteristics.

• The thermal conductivity of AMC can be two or three times higher than cast iron.

• An MMC disc could be 60 % lighter than an equivalent cast iron component.

• The Thermal Diffusivity, which is the rate of heat dissipation compared to that of storage, is four times that of cast iron.

Clearly an impressive material, the performance of which depends on the nature of the composite dispersion.

V. Chengal Redd1, M. Gunasekhar Reddy, Dr. G. Harinath Gowd [17]. A brake disc (or rotor) usually made of cast iron or ceramic composites, is connected to the wheel and/or the axle. Friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc to stop the wheel. The present research is basically deals with the modeling and analysis of solid and ventilated disc brake using ANSYS. Finite element (FE) models of the brake-disc are created and simulated using ANSYS which is based on the finite element method (FEM). In this research Coupled Analysis (Structural & Thermal analysis) is performed in order to find the strength of the disc brake.

The present study can provide a useful design tool and improve the brake performance of disk brake system. Comparing the different results obtained from analysis. It is concluded that ventilated type disk brake is the best possible for the present application.

Baskara Sethupathi P, Muthuvel A, Prakash N, Stanly Wilson Louis [18]. One area that has been examined for weight reduction is vehicle with braking system (BS). The greatest advantages of vehicles, is their ability to recover significant amounts of braking energy using a Braking System (BS). Braking is an effective method to extend brake disc life, minimise disc rotor weight, minimise brake pad wear and to extend the working range of a vehicle. Braking would extend the working range of an vehicle to provided that any extra energy consumption e.g. from increased vehicle mass and system losses did not outweigh the saving from energy recuperation, also reduce duty levels on the brakes themselves, giving advantages including extended brake rotor and friction material life, but more importantly reduced brake mass, minimise brake pad wear. The objective of this research is to define thermal performance on disc brake models. Thermal performance is a key factor which is studied using the model in Finite Element Analysis simulations. The design requirement, including reducing the thickness would affect the temperature distribution and increase stress at the critical area. Based on the relationship obtained between rotor weight, thickness, undercut effect and offset between hat and friction ring, criteria have been established for designing brake discs in a vehicle with braking.

M. Saran Theja & M. Vamsi Krishna [19] Disc (Rotor) brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. The aim of the project is to design, model a disc brake. Modelling is done using Pro/Engineer. Structural and Thermal analysis is to be done on the disc brakes using two materials Stainless Steel and Carbon Steel. Structural analysis is done on the disc brake to validate the strength of the disc brake and thermal analysis is done to analyze the thermal properties. Comparison can be done for displacement, stresses, thermal gradient etc. for the two materials to check which material is best. We are also providing manufacturing process for making disc brake and also preparing prototype. Manufacturing process is done using Pro/Engineer. Pro/Engineer is a 3D modeling software widely used in the design process. ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements.

- The disc brake is a device for slowing or stopping the rotation of wheel. In our project, we have designed and modeled a disc brake.
- Modeling is done using Pro/Engineer. We have performed Structural and Thermal analysis using Stainless steel and Carbon Steel on the disc brake.
- From the structural analysis, by observing stress values for both the materials, both the values are less than their respective yield stresses. So we can decide that our design is safe.
- From thermal analysis, by observing the thermal gradient for both the materials, the value is more for Carbon Steel.
- Thermal gradient is the rate of temperature change on a surface. The rate of temperature change for brake surface using carbon steel is more than that of using stainless steel.
- So they concluded that for our designed disc brake, the better material is carbon steel.

Daanvir Karan Dhir[20] The kinetic energy of the vehicle is converted into mechanical energy while braking which leads to heat dissipation and temperature rise of the disc and the disc-pads. The aim of this investigation was to study the rise in temperature of an automotive disc brake at the time of braking and its effect on disc durability using finite element method.

Application of a specified braking torque on the rotor led to generation of the heat flux. The heat flux generated and the heat transfer coefficient taken into consideration were numerically analyzed, which were then used to calculate the rotor rigidity, maximum temperature rise on the disc rotor. The rotor was further loaded with thermo-mechanical cyclic stresses which were used to analyze the durability and fatigue factor of safety of disc. The influence of variations in disc rotor geometry i.e. holes and airfoil vents in comparison to a simple flange type disc were studied and their effect on maximum temperature rise and disc durability has been investigated by modelling and conducting FEM techniques in Solid works and ANSYS respectively.

Thus from the above results we can say that geometric design of disc is an essential factor in deciding its thermo-mechanical characteristics. The study suggests and justifies the application of disc flange rotors in areas of heavy braking where a larger braking force is required. Discs with geometric patterns (holes and air foil vents) can be used where faster cooling and lightness in weight is preferable.

Jiguang Chen and Fei Gao [21] The distribution of temperatures gradient and thermal stress of brake disc has been simulated by FEM code to make brake disc thermal stress more homogenously. In this study, using moment of inertia to simulate the realistic brake process instead of theoretically predefines the train deceleration rate, nonlinear deceleration rate and thermo-mechanical behaviour has been revealed. The FEM models build upon LS-DYNA thermo-mechanical code and contact algorithm. Non-uniform temperature alone disc radial direction was caused by severe friction in short time and the low heat transfer coefficient of its material. Parametric analysis for disc brakes have been carried out by comparison of grouped brake applications conform to UIC code, the main factor cause the high temperature gradient and thermal stress of brake disc is brake force and its initial speed. The numerical approaches by moment of inertia instead of predefine decelerate to identify the factors influence in disc brakes are performed by a considerable amount of work in this study. Energy transform and heat dissipation process have been performed by thermo-mechanical coupled analytics code. The results reveal the non-uniform temperatures gradient alone disc radial direction and thermal stress caused due to temperature gradient of the disc. By comparison influences of the parameters of normal force and initial speed under given moment of inertia, initial speed is the dominate factor and the normal force dramatically increase the thermal stress and count to be second factor.

Table 1: Parameters of selection materials

Materials / Parameters	Aluminium alloy AA7075/SiC	Carbon-carbon composite	Cast iron
Weight	18.05kg	10.4kg	43.67 kg
Temperature resistance	High	High	Low
Density	2950(kg/m^3),ρ	1700(kg/m^3),ρ	7150(kg/m^3),ρ
Wear resistance	Good	Good	Medium

In today's trains, automobile and motorcycle industry, brake disc is known to be the most effective deceleration device and also known to be the most popular method used. While braking, most of the kinetic energy is converted into thermal energy and this increases the disc temperature.

A high temperature in the disc will lead to the problem of disc warping and will cause an undesirable effect on vehicle handling. The iron brake disks are used in the China Railway High speed 3(CRH3). In particular, brake disks made of aluminum alloys are more preferred because of the weight and the cost effectiveness. Therefore, a reliable design is required to guarantee the service strength under operational conditions and full functioning of the brake disks. According to the experimental results of MINDIVAN et al, among the composites reinforced by SiC particle with 2618, 6082, 7012 and 7075 matrix, the wear resistance of SiC/7075 is the best.

Carbon- Carbon (C-C) composites are a rare group of composite materials that continues to use its properties to the maximum temperatures, lightest weights, inertness, and high degree of toughness compared with other materials. These properties make Carbon- Carbon (C-C) composites perfect for the most advanced applications in the mechanical engineering fields. The disadvantages that limit the distribution and development of Carbon- Carbon (C-C) composites are fabrication processes use are extremely inefficient, and oxidation is fast in an atmosphere at temperature over 400°C. The cost of Carbon- Carbon (C-C) composite varies, but is well in excess. In military applications, high premiums are paid for improved performance rather than price. Carbon- Carbon (C-C) composites businesses predict increases in the next decade in materials usage. Carbon- Carbon (C-C) composites used in the commercial sectors as brakes, heat exchangers, and furnace elements are restricted by cost, unlike in military fields as rocket components, jet engine parts, and brakes. Carbon- Carbon (C-C) composites will remain the highest performance materials through the coming year.

I chose from composite materials the aluminium alloy with silicon carbide AA7075/SiC and carbon-carbon composite based on the property in the table above and the experimental results in the literature review that these materials are appropriate for disc brake

2.2. Summary of the reviewed literatures:

From literature reviews mentioned above are investigated the past research that has been done in many areas related to this work. Most of the literatures listed in this thesis focus on the alternate materials can be used for disc brake of railway vehicles, their mechanical property and some advantage of candidate materials for disc brakes. Also some of literature reviews are related the thermo-mechanical of disc brake and the methods are used, most of them are used ANSYS software based finite element method.

Therefore, it is important to determine with high precision of the temperature distribution and thermal stress of disc brake for different materials and dimension when braking system is applied. Then this research does the comparison for different models of these materials which are the aluminium alloy with silicon carbide AL7075/SiC, carbon-carbon composite and cast iron with same parameters, how they reacts the forces applied in the braking time and suggest the better material.

Thus the Ethiopian railway corporation significantly will be benefited from this work for the reason that knowing the temperature distribution and thermal stress of the brake disc for different materials and dimension after that Addis Ababa LRT can be used these materials as disc brake for the future.

CHAPTER TREE

3. THERMO-MECHANICAL ANALYSIS AND IN PUT DATA COLLECTIONS

3.1. Thermo-mechanical Analysis of disc brake Rotors with an Analytical Method.

3.1.1. Disc Brake

Braking system is one of the important safety components of a vehicle. It is mainly used to decelerate vehicles from an initial speed to a given speed. A friction based braking system is a common device to convert kinetic energy into thermal energy through a friction between the brake pads and the rotor faces. Because high temperatures can lead to overheating of the brake fluid, seals and other components, the stopping capability of a brake increases with the rate at which heat is dissipated due to forced convection and thermal capacity of the system.

The brake disc is a brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The disc brake is usually made of grey cast iron and but may in some cases it can be made from composition such as reinforced carbon-carbon or ceramic matrix composition. This is associated to the wheel or the axle. Brakes convert motion to heat and if the brakes get too hot, they become less effective and this phenomenon is known as brake fade. Disc brakes could be solid or ventilated according to the required performance and condition of the braking.

In this part we talk about the comparison with analytical method of different materials available for disc brake by varying the thickness and radius; so we select the materials which are carbon-carbon composite, aluminium alloy with silicon carbide AL7075/SiC and cast iron the actually used disc brake for AALRT.

These are selected for their thermo-mechanical properties such as strength, hardness, wear resistance, light weight….ect

Then the two new materials are compared with cast iron for same material of pad and same condition, thus after this comparison the study will suggest the better material for disc brake and the AALRT can be used for the future.

3.1.2-Definition of optimization

The optimization is design and operation of systems or process to make them as good as possible in some defined sense. The approaches to optimizing systems are varied and depend on the type of system involved, but the goal of all optimization procedures is to obtain the best results possible subject to restrictions or constraints that are imposed. While a system may be optimized by treating the system itself, by adjusting various parameters of the process in an effort to obtain better results, it is generally more economical to develop a model of the process and to analyze performance changes that result from adjustments in the model.

In many applications, the process to be optimized can be formulated as a mathematical model; with the advent of high speed computers, very large and complex system can be modelled, and optimization can yield substantially improved benefits.

Optimization is applied in virtually all areas of human endeavor, including engineering system design, power system design, transportation system, blending of raw materials, structural design and control systems.

Optimization in its broadest sense can be applied to solve any engineering problem:

- Design of (trains, aircraft) for minimum weight;
- Optimal (minimum time) trajectories for space missions;
- Minimum weight design of structures for earthquake;
- Optimal design of electric networks;
- Optimal production planning, resources allocation, scheduling;
- Shortest route;
- Design of optimum pipeline networks;
- Minimum processing time in production systems;
- Optimal control.

3.2-Thermal Transient Analysis of the Disc Brake

For an isotropic material with internal heat generation, the governing equations for 3D heat conduction equation under transient conditions in Cartesian and Cylindrical coordinate systems are as follows:-

$$kx\frac{d^2T}{dx^2} + ky\frac{d^2T}{dy^2} + kz\frac{d^2T}{dz^2} + Q = \rho Cp\frac{dT}{dT} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where kx, ky and kz are thermal conductivity in x, y and z-directions, respectively, Cp is the specific heat, ρ is the specific mass, Q is internal heat generation rate per unit volume and T is the temperature that varies with the coordinates as well as the time t.

The heat conduction in any direction within the material is governed by Fourier's law of heat conduction:

$$q = -KA\frac{dT}{dx} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Transient thermal analysis requires material properties which include thermal conductivity, specific heat and density. An isotropic material has the same properties in every direction. The boundary conditions are specified by the heat flux entering the model and dissipated from the model by convection or radiation. The initial conditions are specified by the initial nodal temperature value. The heat transfer rate of convection for the disc brake dominates the cooling process specified by Newton's law of cooling:

$qs = -kh(Ts - T\infty)$ Where $Ts = T1(x, y, z) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$

Where h is the convective surface heat transfer coefficient (also known as the film Conductance), T_1 is the specified surface temperature; qs the specified surface heat flux (positive into a surface); Ts the unknown surface temperature, and the convective exchange temperature.

Heat transfer through radiation is calculated from the Stefan-Boltzmann law as:

$q = \epsilon\sigma(T_s^4 - T^4_\infty)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$

Where ϵ is the material's emissivity, σ is Stefan-Boltzmann constant, $T\infty$ is the temperature of the surrounding air.

Heat transfer by radiation can be neglected as it amounts only to 5 % to 10 %. So in this thesis heat transfer through radiation is not considered.

3.3. HEAT FLUX ENTERING IN TO THE DISC

A time-varying heat flux q (t) is applied to the model to simulate the action of the brake pad on the disc. The procedure to determine the time varying heat flux is as follows: -

Braking energy:

$$E_b = \frac{1}{2} m{V_0}^2 + \frac{1}{2} Iw^2 \ldots\ldots 3.5$$

Where $\frac{1}{2} m{V_0}^2$ is energy due to kinetic energy of the vehicle and $\frac{1}{2} Iw^2$ is energy due rotational kinetic energy of rotating parts.

We use $V_0 = Rw$, then our equation become:

$$E_b = \frac{1}{2} m{V_0}^2 \left(1 + \frac{I}{mR^2}\right) \ldots\ldots 3.6$$

$$k = \left(1 + \frac{I}{mR^2}\right)$$

In Some literatures the contribution of the rotating masses of the wheel set and discs is taken to be 10% the tare weight of the axle load of the vehicle [22]. The term $\left(1 + \frac{I}{mR^2}\right)$ accounts to the rotational masses involved and its value equals 1.1 and it is adopted here.

$$E_b = \frac{1}{2} \mathrm{km}{V_0}^2 \ldots\ldots 3.7$$

Braking power:

$$P_b = \frac{E_b}{t_b} \ldots\ldots 3.8$$

$$P_b = \frac{\mathrm{km}{V_0}^2}{2t_b} \ldots\ldots 3.9$$

Heat flux, Q (t) is obtained by dividing the braking power by the swept area of the brake rotor.

$$Q(t) = \frac{\mathrm{km}{V_0}^2}{2At_b} \ldots\ldots 3.10$$

The thermal analysis of the braking system of railway vehicles requires determination of the quantity of heat produced by friction as well as the distribution of this energy between the railway disc and the braking pads.

Generally, the thermal conductivity of material of the brake pads is smaller than that of disc ($k_p <$

kd). The brake disc assumes the most part of the heat, usually more than 90%, through the effective contact surface of the friction coupling. Considering the complexity of the problem and average data processing are limited [23].

Depending on the thermal conductivity of each material which is selected for this thesis, the thermal conductivity of disc and pad will be different. So we can say the material which has the higher thermal conductivity can absorb much heat than the others.

So we can consider the heat transferred for disc and pad 95% and 5% respectively for AA7075/SiC, 93% and 7% respectively for cast iron and 90% and 10% respectively for carbon-carbon composite.

$$Q(\boldsymbol{t}) = \boldsymbol{kd}\frac{\mathrm{km}V_0{}^2}{2At_b} \quad \ldots \quad 3.11$$

3.4. ANALYSIS OF DISC ROTOR FORCE

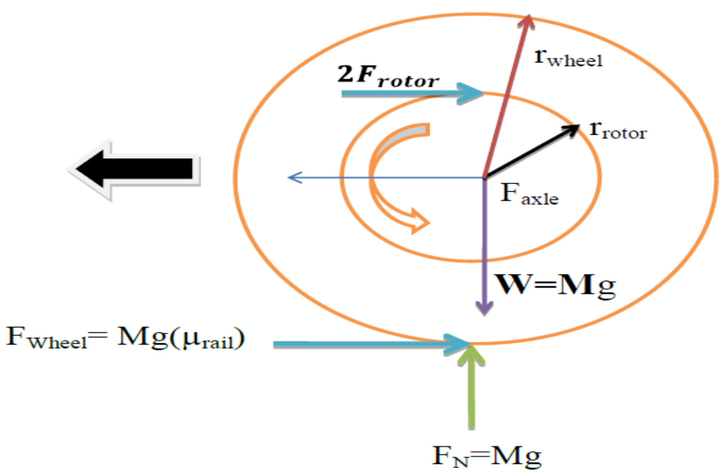


Figure.3.free body diagram of a front wheel-rotor system

A free body diagram of a front wheel-rotor system, fig 3.1, is used to drive the equation of equilibrium. Since large amount of the braking load is born by the front bakes, that amount of kinetic energy and potential energy in to a single disc is given by

$$E_{dissp} = \frac{1}{2} kmV_0{}^2 + S_b mg \sin\alpha \quad \ldots \quad 3.13$$

Where $S_b = \frac{V_0{}^2}{2a}$ braking distance

$E_{dissp} = \frac{1}{2} kmV_0^2 + \frac{V_0^2}{2a} mg \sin\alpha$ ……………………………………………..3.14

The total work of friction force during the whole brake cycle equals with the total heat generated.

$Q_{gen} = E_{dissp} = \int_0^{t_b} P(t)dt$ …………………………………………….…………3.15

$\frac{1}{2} kmV_0^2 + \frac{V_0^2}{2a} mg \sin\alpha = \int_0^{t_b} P(t)dt$ ……………………………………..…………3.16

$\frac{1}{2} kmV_0^2 + \frac{V_0^2}{2a} mg \sin\alpha = (2F_{disc}) \int_0^{t_b} Vdisc(t)\, dt$

$\frac{1}{2} kmV_0^2 + \frac{V_0^2}{2a} mg \sin\alpha = (2F_{disc}) \frac{rdisc}{rwheel}\left[V_0^2 t_b - \frac{1}{2} a t_b^2\right]$

The friction force that work on the disc to retard is:

$F_{disc} = \frac{\frac{1}{2} kmV_0^2 + \frac{V_0^2}{2a} mg \sin\alpha}{2\frac{rdisc}{rwheel}\left[V_0 t_b - \frac{1}{2} a t_b^2\right]}$ ……………………………….....……………………3.17

3.5. DATA COLLECTION AND ANALYSIS

3.5.1 Addis Ababa Light Rail Transit

Addis Ababa Light Rail Transit (AA-LRT) Project consists of E-W & N-S lines, with the total length of main line 31.025km. These two lines operate on the same rail in downtown area for a total length of 2.662km.The ground line mode is mostly applied in rail laying, while elevated line and underground line are also applied in some sections.

The entire line has 39 stations, consisting of 9 elevated stations (including 5 in the section that uses the same rail, 1 on E-W line, and 3 on S-N line), 2 underground stations, 1 semi-underground, and Ground stations are designed on ground line section, including 27 ground stations along the line (13 ground stations on N-S line, and 14 ground stations on E-W line).

The east-west line phase I project starts from Ayat and ends at Torhailoch. Thetotal length is 17.4km. There are 22 stations, among which 5 are elevated stations, 1 underground station and 16 ground stations. The depot locates at the west ends of the project.

The south-north line phase I project starts from Menelik II Square and ends at Kaliti. The total length is 16.97km. There are 22 stations, among which 9 are elevated stations （5 common stations at the common line, 2 underground station and 11 ground stations. The depot locates at the south end of the project.

For ensuring the traction power supply on the main line as well as the power supply for the station equipment, 18 substations are set up along the line, including 17 traction and decompression substations, and 1 decompression substation.

Table2: Slope/Gradient some of AA-LRT Station (E-W Route) [23]

No	Station names	Station symbol	Slope/gradient	Station types
1	Ayat 2	EW1	0.0333[1.905°]	Ground station[- down]
2	CMC 1	EW4	0.0483[2.767°]	Ground station[+ up]
3	St. Michael Church	EW5	0.0185[1.058°]	Ground station
4	Mexico Square	EW19	0.0278[1.591°]	Elevated station
5	Coca Cola	EW21	0.0227[1.302°]	Ground station

3.5.2 VEHICLE BRAKING ON A RAIL TRACK

3.5.2.1 BRAKING ON A STRAIGHT TRACK

When braking on a flat surface the train has only kinetic energy of the vehicle and rotational kinetic energy of the rotating parts because the train potential energy is neglected as the gradient of the train is set to be zero. Due to this kinetic energy the heat is developed between rotor and pad due to friction. The heat energy during this time is calculated only from the kinetic energy of the vehicle and rotational kinetic energy of the rotating parts.

Using Newton's second law of motion the equation of motion when a vehicle moving along a straight track is

$$m_a = F_T - F_D - F_R \qquad \text{......3.18}$$

Where m is the total mass of the vehicles including the passenger weight

F_T = traction force

F_D = drag force

F_R = rolling resistance force

The heat flux generated when the vehicle moving on straight track during the braking cycle is:

$$Q(\boldsymbol{t}) = \boldsymbol{k_d} \frac{\boldsymbol{kmV_0}^2}{\boldsymbol{2At_b}} \quad (3.19)$$

3.5.2.2 BRAKING ON INCLINED TRACK

The alignment of the rail way track is not only straight but also has a different gradient and curves. Now the train has both kinetic energy and potential energy due to its motion and its inclination /gradient which intern increases the heat energy dissipation from the contact surface to the surrounding. The gradient increases and decreases the dissipation of heat energy depending on the direction of the movement. When the vehicle is moving along the downhill the gradient increases the heat energy while when it moves along the uphill the gradient decreases the heat energy. The total energy will be the summation of all the three energies.

Using Newton's second law of motion the equation of motion when a vehicle moving in the upward inclined plane track is:

$$m_{at} = F_T - F_D - F_R - F_G \quad (3.20)$$

Where m is the total mass of the vehicles including the passenger weight

F_T = traction force

F_D = drag force

F_R = rolling force resistance

F_G = Total weight component in the direction of the inclined plane.

a_t = train acceleration

The heat flux generated when the vehicle moving on uphill track during the braking cycle is:

$$Q(t)=kd\left[\frac{kmV_0^{\ 2}}{2At_b}-\frac{S_b mg\sin\alpha}{At_b}\right]\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.21$$

Using Newton's second law of motion the equation of motion when a vehicle moving in the downward inclined plane track is:

$$m_{at} = F_T - F_D - F_R + F_G\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.22$$

Where m is the total mass of the vehicles including the passenger weight

F_T = traction force

F_D = drag force

F_R = rolling force resistance

F_G = Total weight component in the direction of the inclined plane.

a_t = train acceleration

The heat flux generated when the vehicle moving on downhill track during the braking cycle is:

$$Q(t)=kd\left[\frac{kmV_0^{\ 2}}{2At_b}+\frac{S_b mg\sin\alpha}{At_b}\right]\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.23$$

From equations 3.19, 3.21, 3.23, the heat flux entering the disc rotor when the vehicle moving up the gradient is less that of moving on a straight track and down the gradient. Maximum heat flux is occurred when the vehicle moving in the downhill direction of the track having maximum gradient of 1.905° which is Ayat2 (EW1) station.

So the thermo-mechanical analysis of the disc brake place under the maximum operation speed and load during service and emergency braking will be done for this station.

3.5.3 SEATING AND LOADING CAPACITY OF THE TRAIN VEHICLE

Table 3: Seating capacity of the train [24]

Number of passengers (persons)	Seated	Standing	Total
Seats (AW1)	65	**0**	65
Seating capacity (AW2)(standing:6persons/m^2)	65	189	254
Overload capacity (AW3)(standing: 8 persons/m^2)	65	252	317
Unacceptable overloading capacity (AW4)(standing: 10 persons/m^2)	101	319	420

Table 4: Weights of the train [24]

Loads	Car body weight	Passenger weight	Total weight
Empty vehicle (t)	44	0	44
Seating capacity (t)	44	15.24	59.24
Recommended Overload capacity (t)	44	19.02	63.02
abnormal overloading capacity(t)	44	25.2	69.2

Note: Take 60kg as average weight of each passenger.

Table 5.Vehicle properties [24]

Item		Quantity
Mass of the vehicle(m),kg	Empty load(vehicle mass)	44000
	Normal load	59240
	Over load	63020
	Abnormal over load	69200
Vehicle speed (V_0)Km/h	Normal speed	40
	Maximum speed	70
	Over speed	80.3
Deceleration a[m/s^2]		1.1 for service
		2.0 for emergency
Radius of the wheel, mm		330

3.6 CALCULATION OF HEAT FLUX GENERATION OF AYAT2 (EW2) STATION

3.6.1.1 The heat flux generated when the vehicle moving on AYAT2 during the braking cycle is:

$$Q(t) = kd\left[\frac{kmV_0^{\,2}}{2At_b} + \frac{S_b mg\sin\alpha}{At_b}\right] \text{………………………………………..………..} 3.32$$

$$S_b = \frac{V_0^{\,2}}{2a}$$

$$Q(t) = kd\left[\frac{kmV_0^{\,2}}{2At_b} + \frac{V_0^{\,2} mg\sin\alpha}{2At_b a}\right]$$

$$Q(t) = kd\,\frac{mV_0^2}{2At_b}\left[k + \frac{g\sin\alpha}{a}\right]$$

3.6.1.2 CALCULATION OF HEAT FLUX AT ABNORMAL OVER LOAD WITH EMERGENCY BRAKING FROM MAXIMUM SPEED OPERATION AT AYAT2 (EW2)

Where m is the total mass of vehicle m = 69200Kg for abnormal over load

V_0 = maximum operation speed of the vehicle =70Km/h = 19.444m/s

a= deceleration for emergency brake = 2.0m/s^2

$t_b = \frac{V_0}{a} = \frac{19.444}{2}$ = 9.722sec

A_d = contact swept area =2π (r_{op}^2- r_{ip}^2)

Where r_{op} outer pad radius and r_{ip} inner pad radius

$A_d = 2\pi(r_{op}^2 - r_{ip}^2) = 2\pi\ (180^2 - 110^{2)}) = 127548$ mm $= 0.128 m^2$

k = correction factor for rotating parts = 1.1

k_d= proportion of heat entering the disc brake

g = acceleration due to gravity = 9.81m/s^2

α = inclination at AYAT2 = 1.905°

$$Q(\boldsymbol{t}) = \boldsymbol{k_d}\,\frac{(\mathbf{19.444})^2 * \mathbf{69200}}{\mathbf{2} * \mathbf{0.128} * \mathbf{9.722}}\left[\mathbf{1.1} + \frac{\mathbf{9.81}\,\mathbf{sin}(\mathbf{1.905})}{\mathbf{2}}\right]$$

$$Q(\boldsymbol{t}) = \boldsymbol{k_{d*}}\,\mathbf{11254771}(\mathbf{w/m^2})$$

For k_d = 0.9 for carbon-carbon composite.

$$Q(\boldsymbol{t}) = \mathbf{10129293.9}\ (\mathbf{w/m^2})$$

For k_d= 0.93 for grey cast iron

$$Q(\boldsymbol{t}) = \mathbf{10466937.03}\ (\mathbf{w/m^2})$$

For k_d= 0.95 for aluminum alloy with silicon AA7075/SiC.

$$Q(\boldsymbol{t}) = \mathbf{10692032.45}\ (\mathbf{w/m^2})$$

The weight distribution of the vehicle considered is equally distributed between the front and rear bogies. The vehicle is equipped with eight mechanical disc brakes. Hence, only 1/8 of the whole heat flux is applied to one disc from the forward part of the carriage.

3.6.2. CALCULATION OF FORCE ACTING ON THE DISC BRAKE

From Eq.3.17 the braking force on the disc is equal to

$$F_{disc} = \frac{\frac{1}{2}KmV_0^2 + \frac{V_0^2}{2a}\text{mg}\ \sin\alpha}{2\frac{rdisc}{rwheel}\left[V_0 t_b - \frac{1}{2}a t_b{}^2\right]}$$

Braking force on the disc at maximum operation speed and over load at emergency brake

V_0 =70km/h = 19.444m/s and m = 69200kg

$$F_{disc} = \frac{\frac{1}{2}*1.1*69200*(19.444^2)+\frac{19.444^2}{2*2}*69200*9.81\ \sin(1.905)}{2\frac{0.145}{0.33}\left[19.444*9.722 - \frac{1}{2}*2*(9.722)^2\right]}$$

F_{disc} = 198917.932N

The weight distribution of the vehicle considered is equally distributed between on the front and rear bogies. The vehicle is equipped with eight mechanical disc brakes. Hence, only 1/8 of the whole brake force is applied to one disc from the forward part of the carriage.

F_{disc} = 24864.742N

When braking is applied there will be weight transfer from the rear part to the front part of vehicle, this phenomena cause much loading on the front wheels and the rear one are less loaded. So the application of brake force on the disc brake will be distributed accordingly to the load otherwise the rear wheels will be locked and then skid.

So in this situation i consider the braking phase will apply accordingly to the load of the wheels.

3.6.3. CALCULATION OF CALIPER PRESSURE

The total rotor force applied to both the inboard and out board rotors can be used to calculate the caliper clamping force required to stop the vehicle. According to DIN EN ISO1183 the value μ = 0.32 of the friction coefficient for materials of the disc and the pad for A.A. LRT is taken as the recommended value.

$$P = \frac{Fdisc}{\mu * A\mathrm{p}}$$

Ap is the area of the pad

For a vehicle moving at maximum operation speed

$$P = \frac{24864.742}{0.32 * 0.01225} = 6343046.429 = 6.343MP_a$$

Table6. Summary of heat flux, force on the disc and pressure of caliper at maximum operations train speed and abnormal load.

Velocity (m/s^2)	Vehicle mass(Kg) for abnormal overdoing	Heat flux $Q(t)$ (w/m^2) on one disc			Force(N) on one disc	Pressure (MPa) On one disc
		For model 1 R=170 and thick =50mm	For model 2 R=180 and thick =60mm	For model 3 R=190 and thick=70mm		
19.444	69200	Kd=90% 1803683.23 Kd=93% 1863806.01 Kd=95% 1903887.86	Kd=90% 1493675.175 Kd=93% 1543464.348 Kd=95% 1576657.13	Kd=90% 1266161.74 Kd=93% 1308367.13 Kd=95% 1336504.06	24864.742	6.343

3.6.4. CALCULATION OF COEFFICIENT OF HEAT TRANSFER

To calculate the convective film coefficient (coefficient of heat transfer) as a function of the railway vehicle velocity *v*, the following formula [25] should be used:

$$h = \frac{0.037 * Kair}{2R} * Re^{0.8} * Pr^{0.33} \qquad \text{……3.34}$$

But the Reynolds number *Re* and Prandtle *Pr* number are given as following:

$$\mathbf{Re} = \frac{2\rho air * V * R}{\mu\, air} = \mathbf{443411.63} \qquad \text{……3.35}$$

Pr = $\frac{Cpair * \mu\, air}{Kair}$ **=0.715**…………………………………………………………3.36

Where K air conductivity of air = 0.02601 w/mk

$Cpair$ = specific heat capacity =1006.284J/kgK

ρair = density of air 1.17kg/m^3

$\mu\ air$ = dynamic viscosity =$1.847*10^{-5}$Ns/m^2

With temperature T = 298K, R is the radius of the rotor disc and maximum operation speed

V = 19.444m/s^2

For R=170mm model 1

h =$\frac{0.037*0.02601}{2*0.17}*(418777.65)^{0.8} * (0.715)^{0.33}$ = 79.68w/m^2

For R=180mm model 2

h =$\frac{0.037*0.02601}{2*0.18}*(443411.63)^{0.8} * (0.715)^{0.33}$ = 78.778 w/m^2

For R=190mm model 3

h =$\frac{0.037*0.02601}{2*0.19}*(468045.61)^{0.8} * (0.715)^{0.33}$ = 77.93 w/m^2

Table6.1: coefficient of heat transfer for different models.

Different models	Model 1 r=170mm Thick=50mm	Model r=180mm Thick=60mm	Model 3 r=190mm Thick=70mm
Coefficient of heat transfer (h)	79.68w/m^2	78.778 w/m^2	77.93 w/m^2

CHAPTER FOUR

4. MODELING AND ANALYSIS USING FINITE ELEMENT METHOD

4.1 Modelling software

There are different software's available for modeling some of them are: Solid works, CFD GAMBIT, ANSYS work bench and CATIA etc.

CATIA V5 (computer aided three dimensional interactive application) a multi-platform is used as the modeling tool in this project.

4.1.2 CATIA V5 part Modelling

The CATIA V5 is a 3-D parametric solid modeler with both part and assembly modeling capabilities. CATIA V5 to model piece parts and then combines them into more complex assemblies. With CATIA V5 a part is designed by sketching its components shapes and defining their size shape and interrelationships. Since CATIA V5 has parametric features, you can change one feature and all related features are automatically updated to reflect the change and its effects throughout the part. It can be used to create angular shaped part, to which 3D surface can be applied to create hybrid parts consisting of mixture of angular and curved shapes. This provides the ability to create model designs with shapes of varying types.

Assemblies can be created from parts, either combined individually or grouped in subassemblies. The CATIA V5 builds these individual parts and subassemblies into an assembly in a hierarchical manner according to relationships defined constrains. As in part modeling, the parametric relationship allows you to quickly update an entire assembly based on a change in one of its parts. And save the model as IGS profile for importing to the ANSYS work bench for finite element analysis.

4.2 THERMAL AND STRUCTURAL ANALYSIS

A Thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. A transient thermal analysis determines the temperature distribution and other thermal quantity under conditions that vary over a period of time which is this thesis focuses.

4.2.1 STRUCTURAL ANALYSIS

Using the result obtained from thermal and applied pressure Transient structural analysis to see the effect of temperature on the body structure.

To simplify the analysis, several assumptions were also been made as follows:

- All kinetic energy at disc brake rotor surface is converted into frictional heat or heat flux.
- The heat transfer involved in this analysis takes place only by conduction and convection.
- Heat transfer by radiation can be neglected as it amounts only to 5 % to 10 %.
- The disc material is considered as homogeneous and isotropic.
- Inertia and body force effects are negligible during the analysis.
- In this analysis, the ambient temperature and initial temperature is set to 25°C.
- Uniform pressure distribution generated by the brake pad onto the disc brake surface is
- Considered.
- No wear
- The dimensions of the holes of disc are very small so they are not considered in the contact surface between the disc and pad.

Table 7.Geometrical Dimensions of disc and pad [actual measured dimension]

Items	Disc	Pad
Inner radius, mm	110	110
Outer radius, mm	180	180
Thickness, mm	60	20
Effective rotor radius, mm	145	
Surface disc swept Area by the pad A_d,m^2	0.128	
Pad area A_p, m^2	0.01225	
coefficient of friction, μ	0.32	

Based on the dimension of disc brake used for AALRT this thesis will vary this dimension for different materials to get the optimum material for this brake disc, so the range will be:

Thickness (mm)	Radius (mm)
50	170
60	180
70	190

Table 8.Properties of the materials of disc and pad

PROPERTIES	DISC			PAD
	Grey cast iron	SiC/Al7075 composite	Carbon-carbon composite	Ceramic Fiber Al2O3
DENSITY(Kg/m^3), ρ	7150	2950	1700	3800
Elastic modulus - *E [G Pa]*	140	233	95	325
THERMAL CONDUCTIVITY(W/m.K), k	52	60	40	30
SPECIFIC HEAT CAPACITY (J/Kg.K),Cp	423	650	760	700
POSSION’S RATIO, υ	0.24	0.13	0.32	0.22

4.3 GEOMETRICAL MODELING OF DISC AND PAD USISG CATIA SOFTWARE

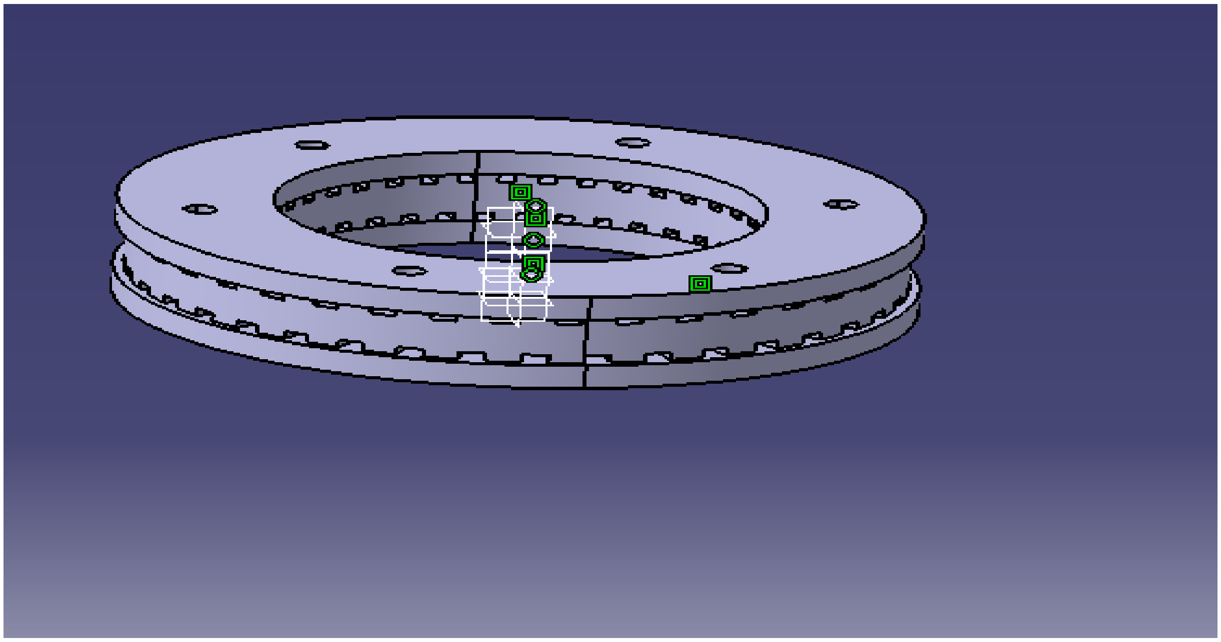


Figure 4.1 disc brake

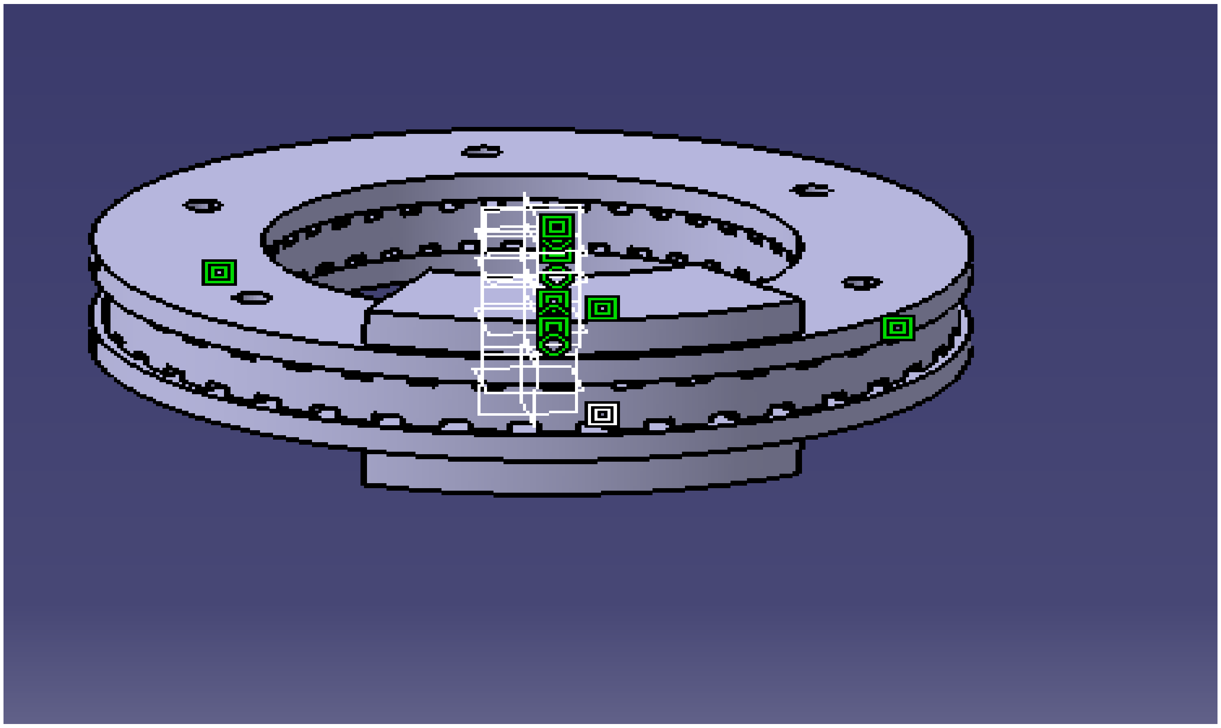


Figure 4.2 Assembly of Disc brake and Pad

4.4 CREATING A FINITE ELEMENT MESH

Meshing is discretizing the solid object to finest parts to perform the analysis to get the precise value at each and every elements of the meshed object. Since the disc and pad are 3D element the appropriate meshing method will be volume mesh so that all the volume of the disc-pad assembly is discretized to the smallest part of the disc-pad assembly and refined the contact area of the disc and pad.

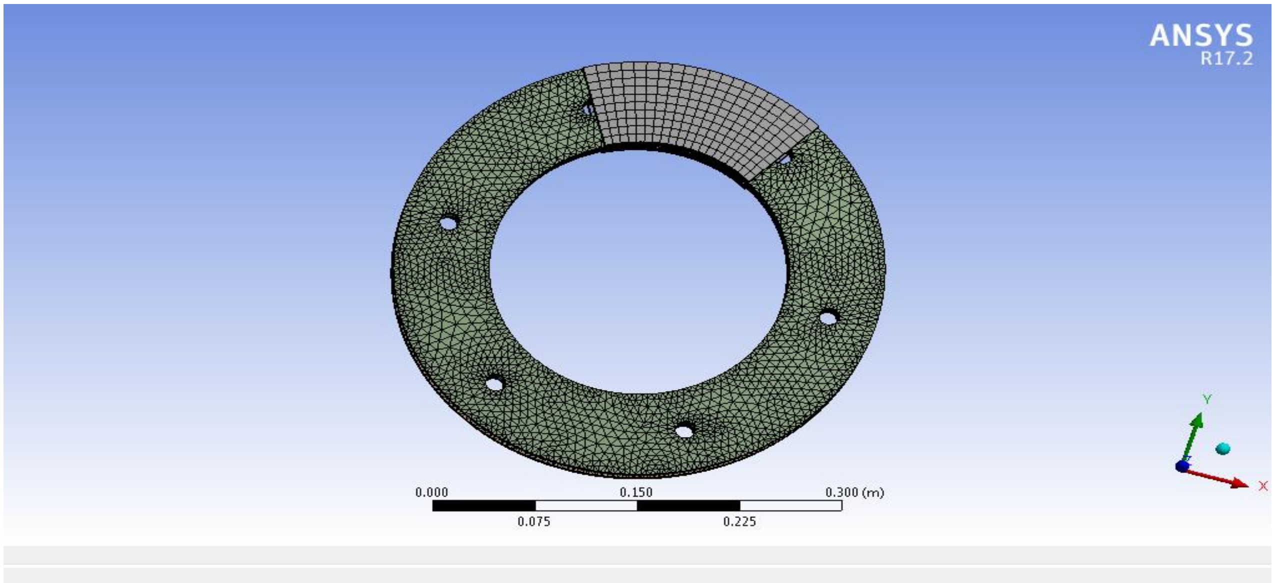


Figure 4.3 meshing of the assembly

4.5. APPLYING LOADS AND BOUNDRY CONDITIONS

In thermal and structural analysis of disc brake, we have to apply thermal and boundary conditions on 3-D disc model of the disc brake.

4.5.1 Thermal loads and boundary conditions

After completion of the finite element model, it was necessary to apply loads and boundary conditions to the model. The analyzed railway disc brake is subjected to the following loads:

- The initial temperature of the disc and the pads is 25 °C.
- The surface convection condition is applied at all surfaces of the disc with the values of the convection coefficient (h).
- The heat flux into the brake disc during braking

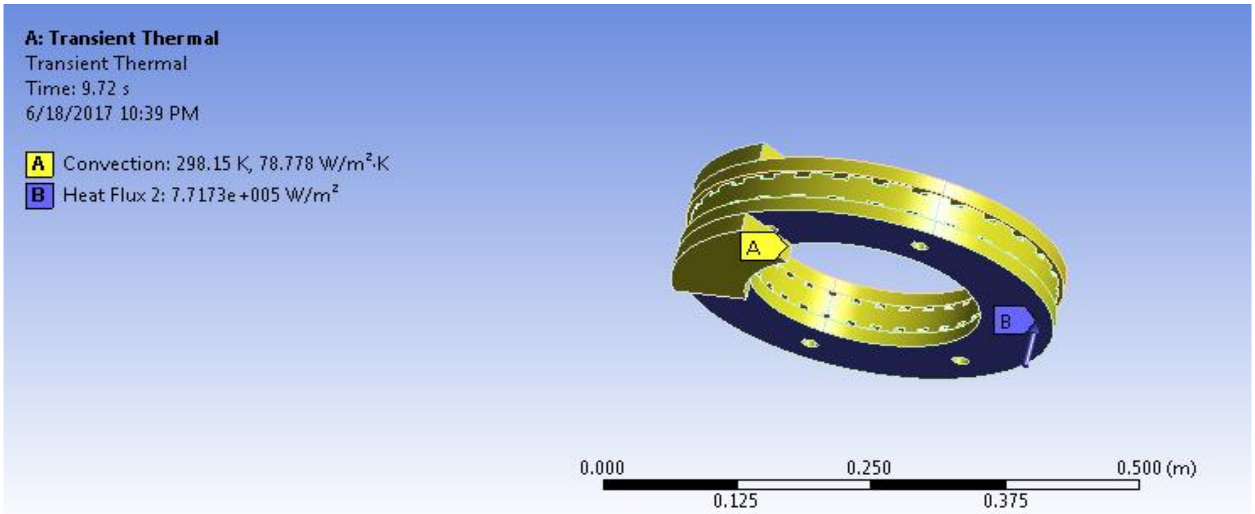


Figure 4.4 Thermal loads and boundary conditions

4.5.2 Structural loads and boundary conditions

All the nodes on the inner disc radius are fixed. So the nodal displacements on the inner disc radius become zero.i.e. In radial, axial, and angular directions. The pads are fixed except in Z-direction.

- The pressure on the rubbing contact surfaces of the disc and brake pad was calculated before.
- Fixing the disc on the axle and the holes

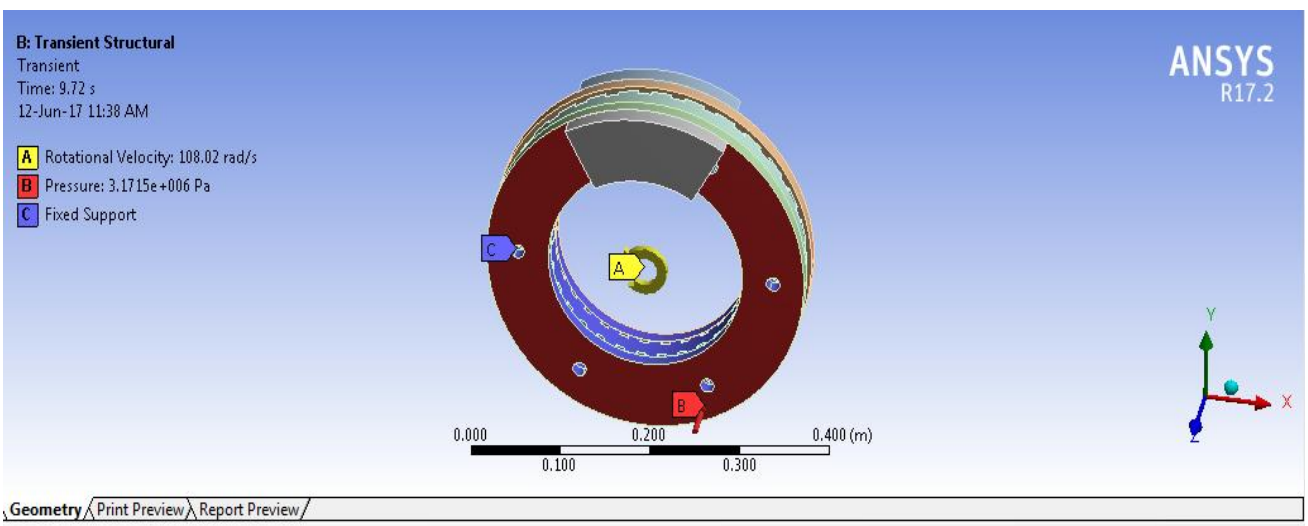


Figure 4.5 Structural loads and boundary conditions.

We change the dimension of disc brake used in AALRT to find the optimum model because our train is over loaded most of time, much more the designed capacity load and the cast iron which is actually used has high density. So the objective of this work is to find the better model and material for the future to our AALRT.

The materials select in this study, aluminium alloy with silicon carbide AL7075/SiC and carbon-carbon composite are lighter than cast iron and they are already used as disc brake by China railway high speed.In the present research, the mass of the brake disc made from SiC/Al7075 composite is 28.05Kg and the mass of the brake disc made from grey cast iron for A.A LRT brake disc equals 62.332Kg. Hence 34.282Kg of A.A LRT brake disc mass will be reduced from a single brake disc rotor. One train has 8 discs brakes so we can reduce 274.26kg from total weight of the vehicle.

Table8.1: Different dimension of disc brake using by others countries.

Other countries	**Dimensions of dis brake**	
	Radius (mm)	Thickness(mm)
CHINA railway [26]	230-350	60-170
INDIAN railway [27]	247	110
FRANCE TGV [28]	320	45

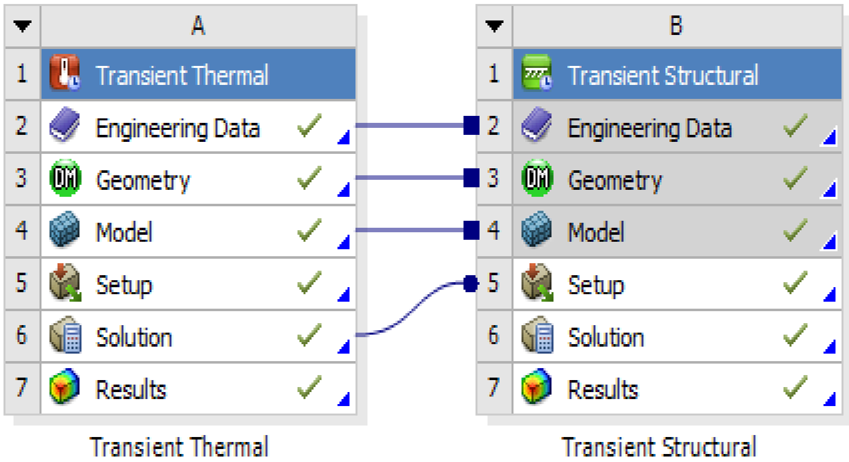


Figure 4.5.1 the connection the thermal to the structure

4.6 RESULTS AND DISCUSIONS

4.6.1. Thermal analysis results

For model 1

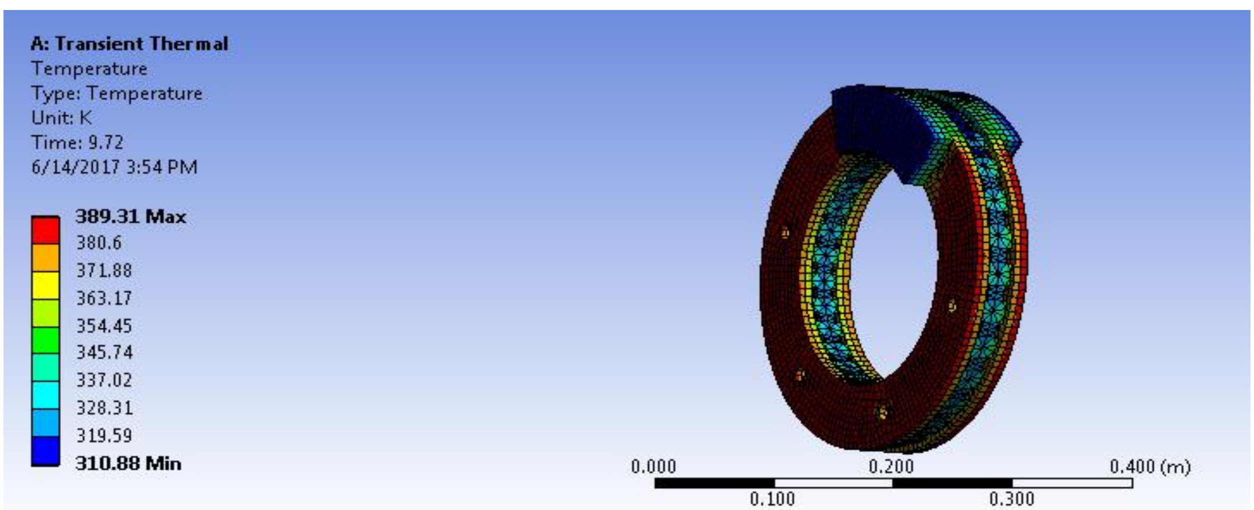


Figure 4.6 M1.1.a.Temperature of cast iron

The temperature distribution for cast iron which is maximum at the contact surface between the disc and pad

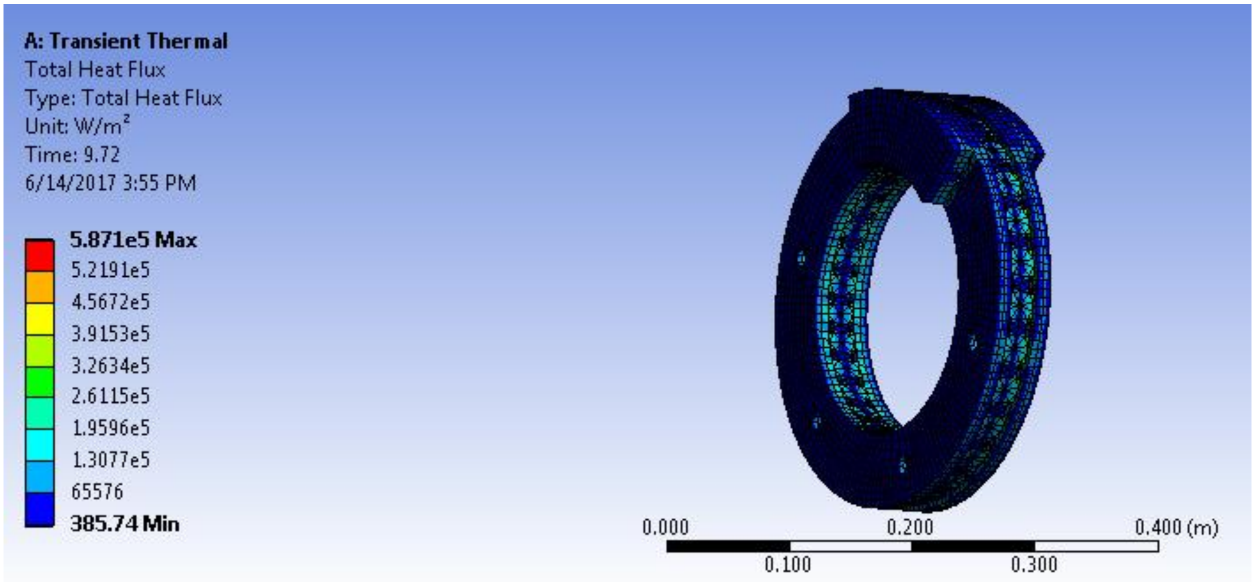


Figure 4.7 M 1.1.b total heat flux of cast iron.

The total heat flux of cast iron which maximum at the inner part of the disc bake.

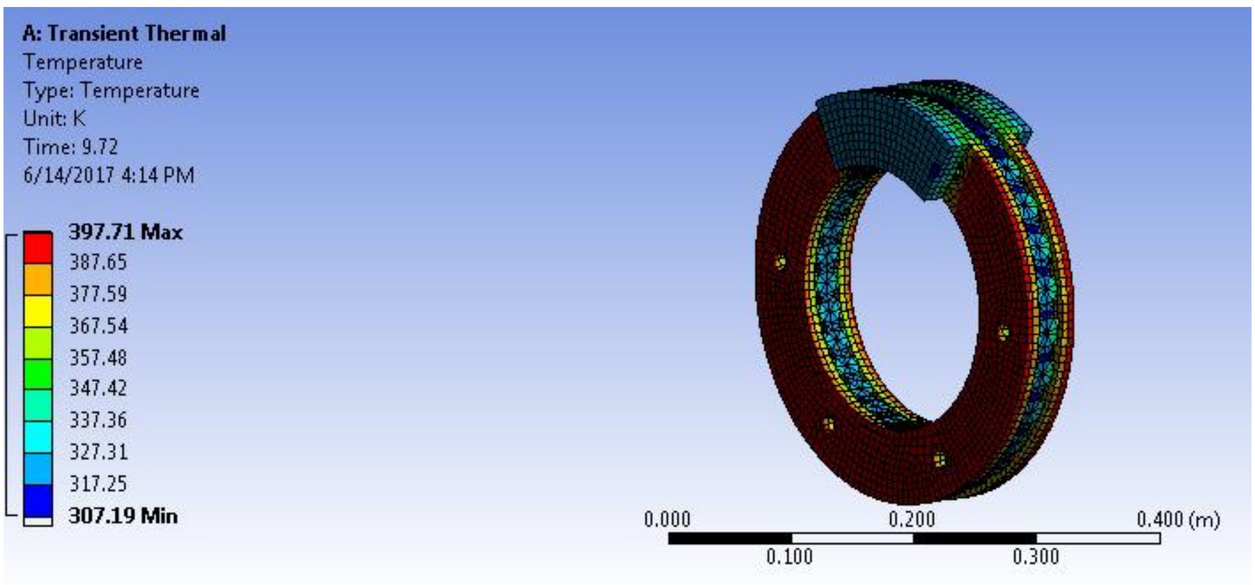


Figure 4.8 M1.2.a temperature of carbon-carbon composite.

This figure shows as the distribution of temperature for carbon-carbon composite which has the advantage to resist high temperature.

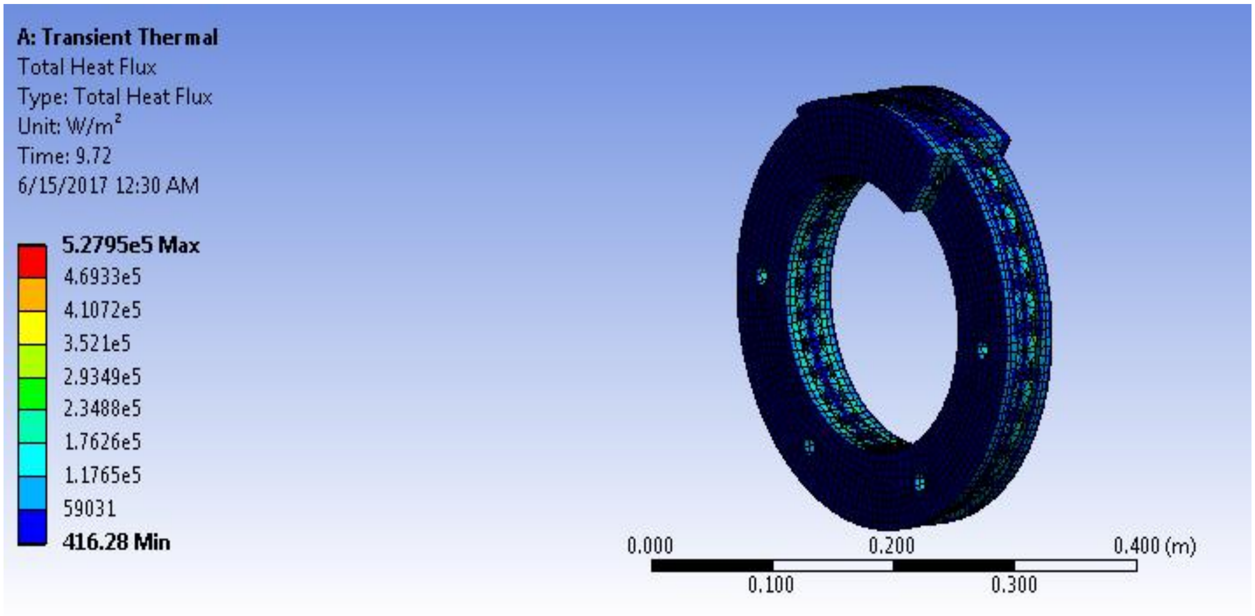


Figure 4.9 M1.2.b. total heat flux of carbon-carbon composite

This figure shows as the total heat flux for carbon-carbon composite which is less than the heat flux of cast iron.

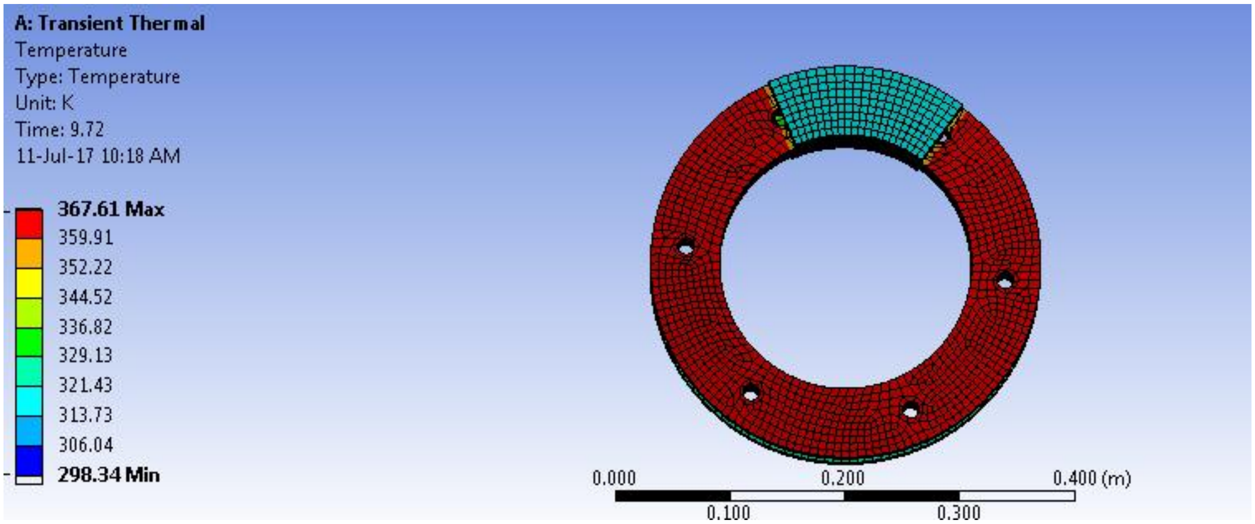


Figure 4.10 M1.3.a.Temperature of SiC/AL7075 composite.

The maximum temperature of SiC/AL7075 composite is the minimum temperature for model 1.

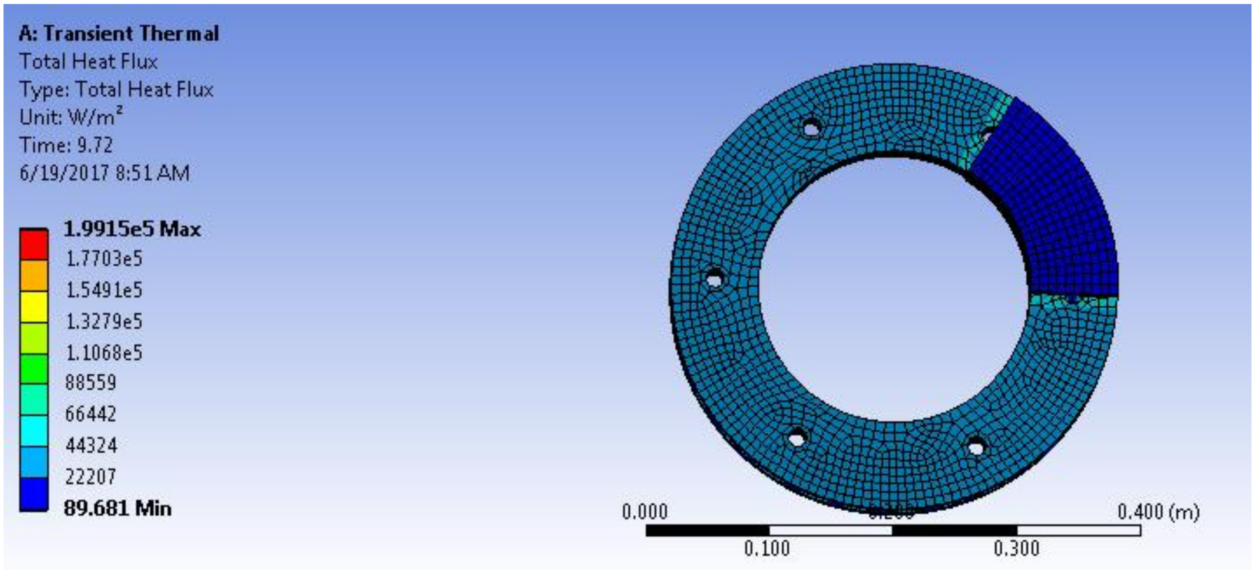


Figure 4.11 M1.3.b. total heat flux of SiC/AL7075 composite.

The heat flux of SiCAL7075 composite and it is the minimum heat flux for model 1

For model 2

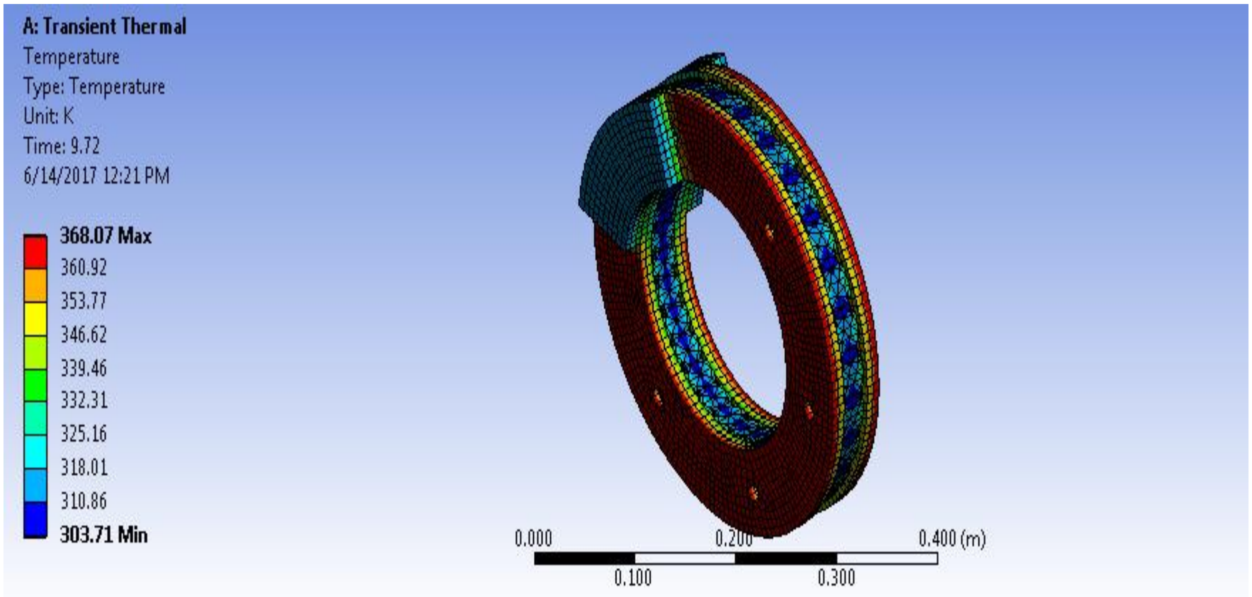


Figure 4.12 M 2.1.a. Temperature of cast iron.

The maximum temperature of cast iron in model 2 is less than the temperature in model 1.

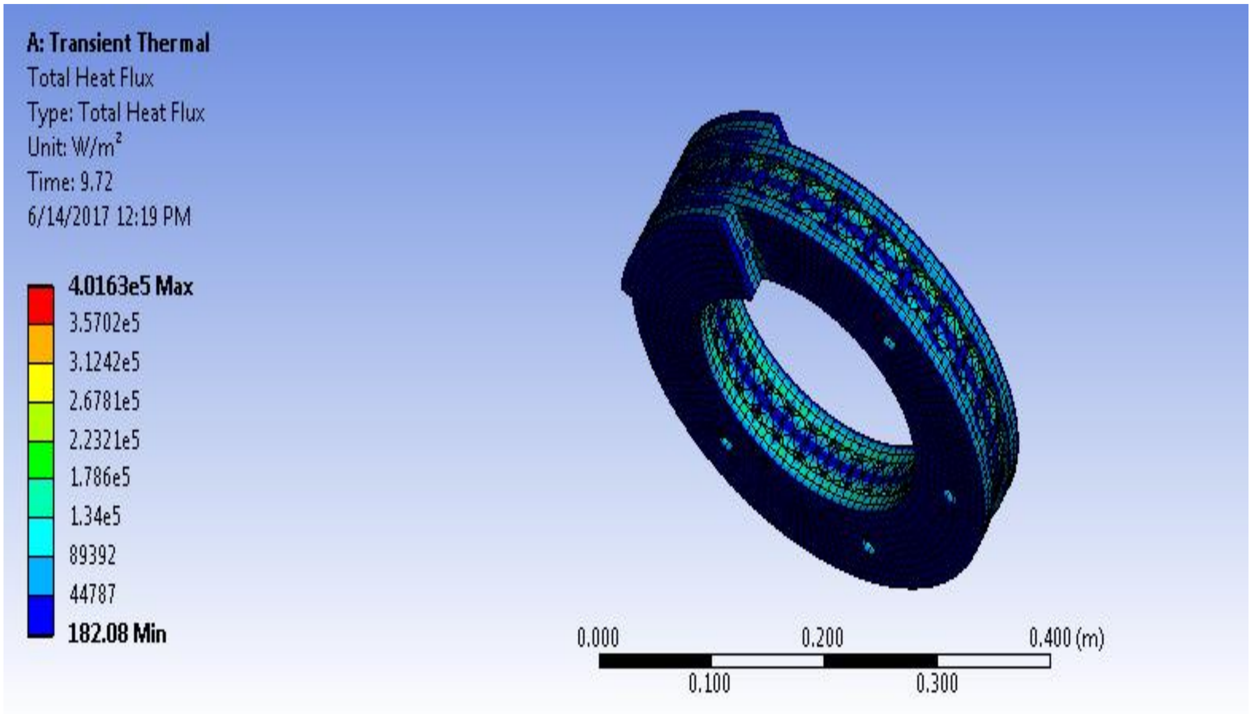


Figure 4.13 M 2.1.b total heat flux of cast iron.

The maximum heat flux of cast iron for model 2 is less than the one for model 1.

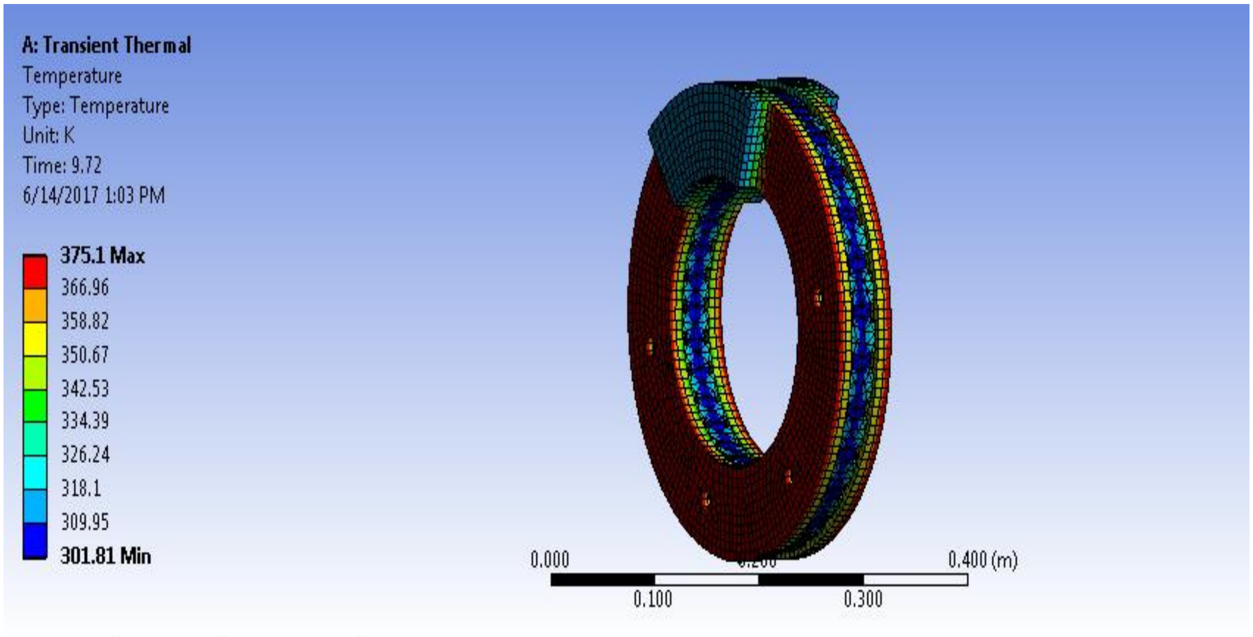


Figure 4.14 M2.2.a temperature of carbon-carbon composite

This figure shows the temperature distribution of carbon-carbon composite which is maximum at the contact surface.

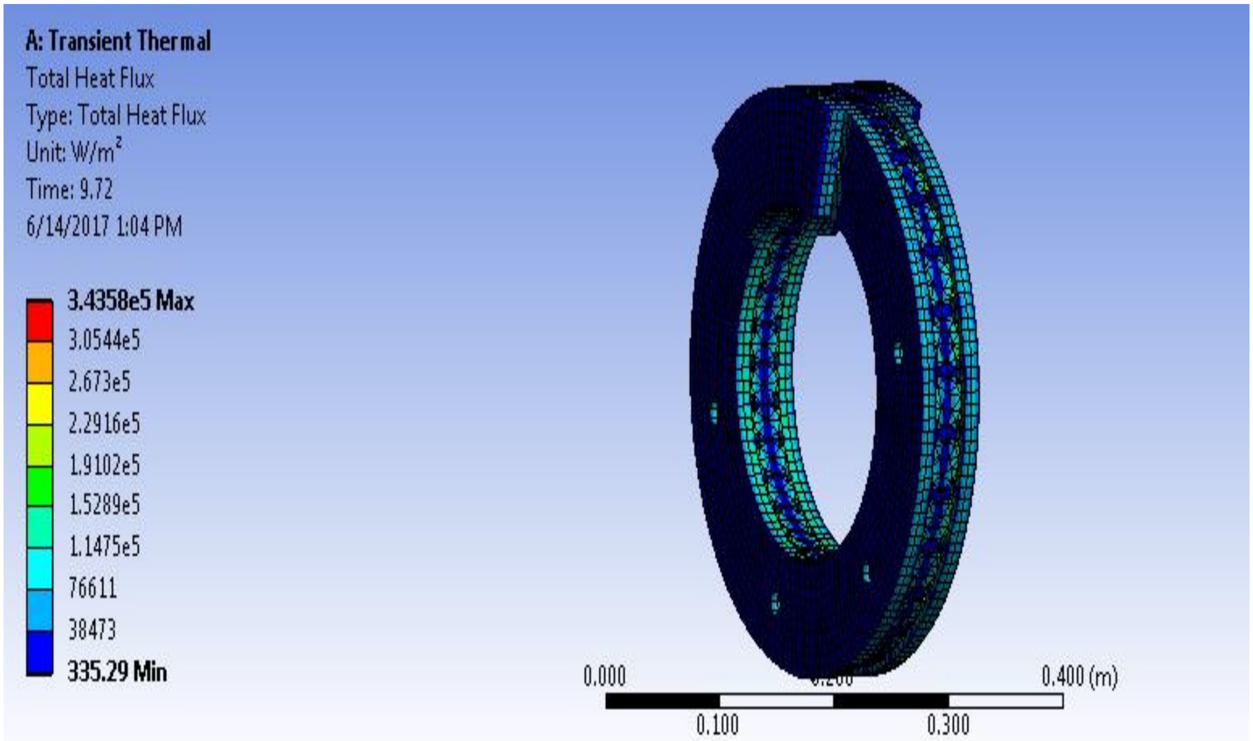


Figure 4.15 M.2.2.b. total heat flux of carbon-carbon composite

This figure shows the distribution of heat flux which is maximum at the inner part of disc brake.

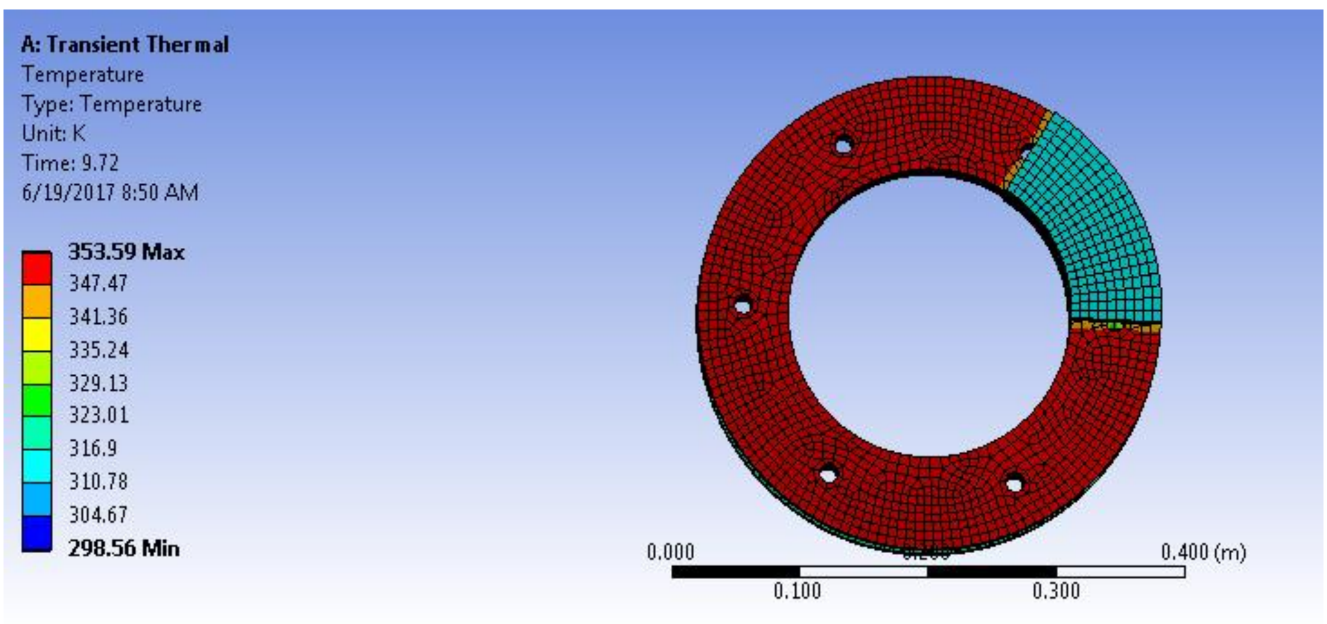


Figure 4.16 M 2.3.a. Temperature of SiC/AL7075 composite.

The distribution of temperature of SiC/AL7075 composite and this material has temperature for model 2.

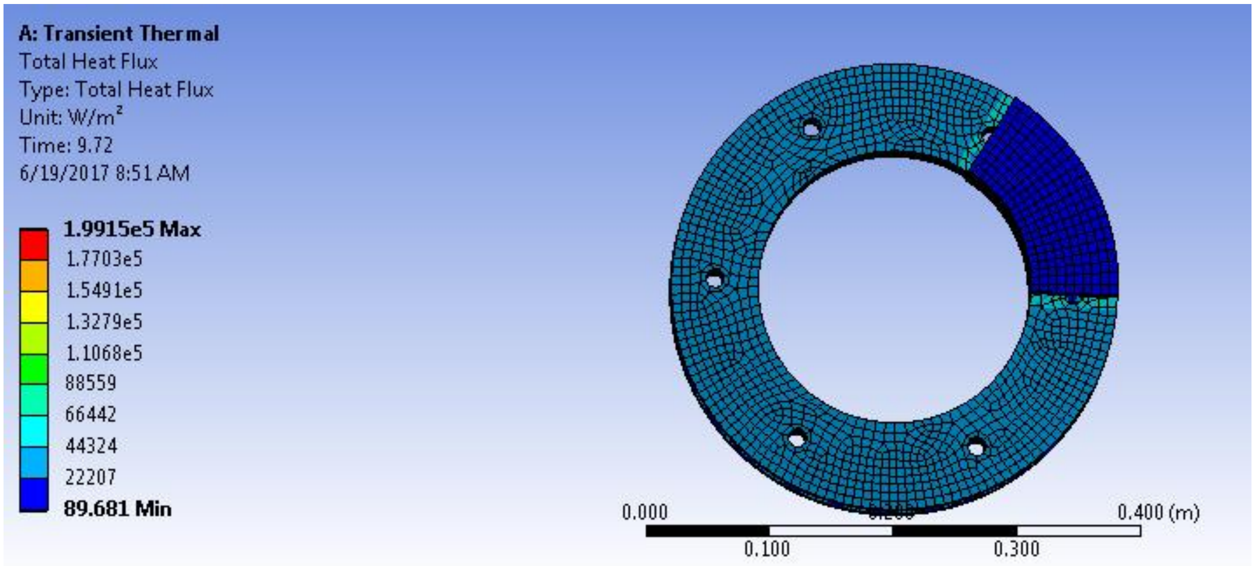


Figure 4.17 M 2.3.b. total heat flux of SiC/AL7075 composite.

This material has the smallest heat flux for model 2.

For model 3

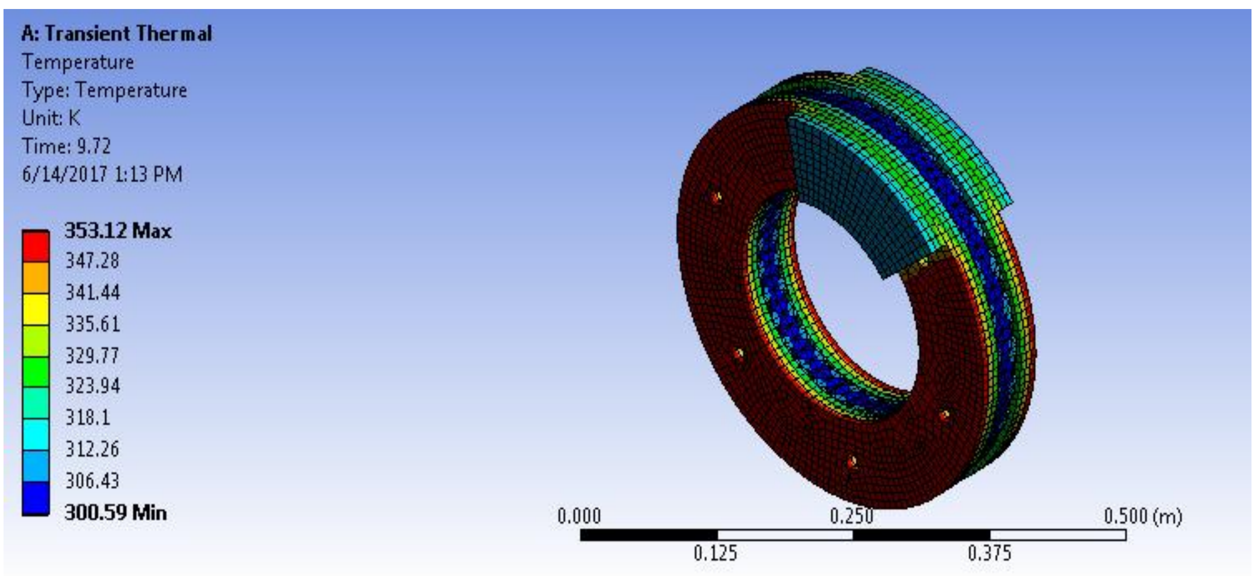


Figure 4.18 M 3.1.a. Temperature of cast iron.

This figure shows as the temperature distribution of cast iron for model 3.

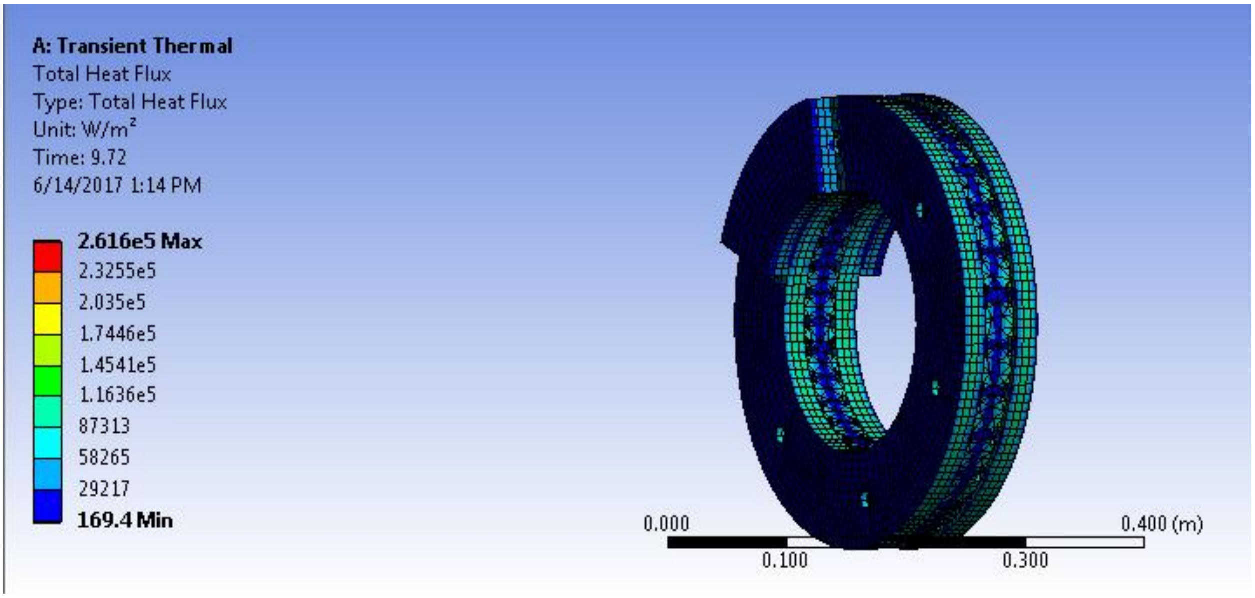


Figure 4.19 M 3.1.b total heat flux of cast iron

This figure shows the total heat flux of cast iron for model 3 which is less than the heat flux for model 2.

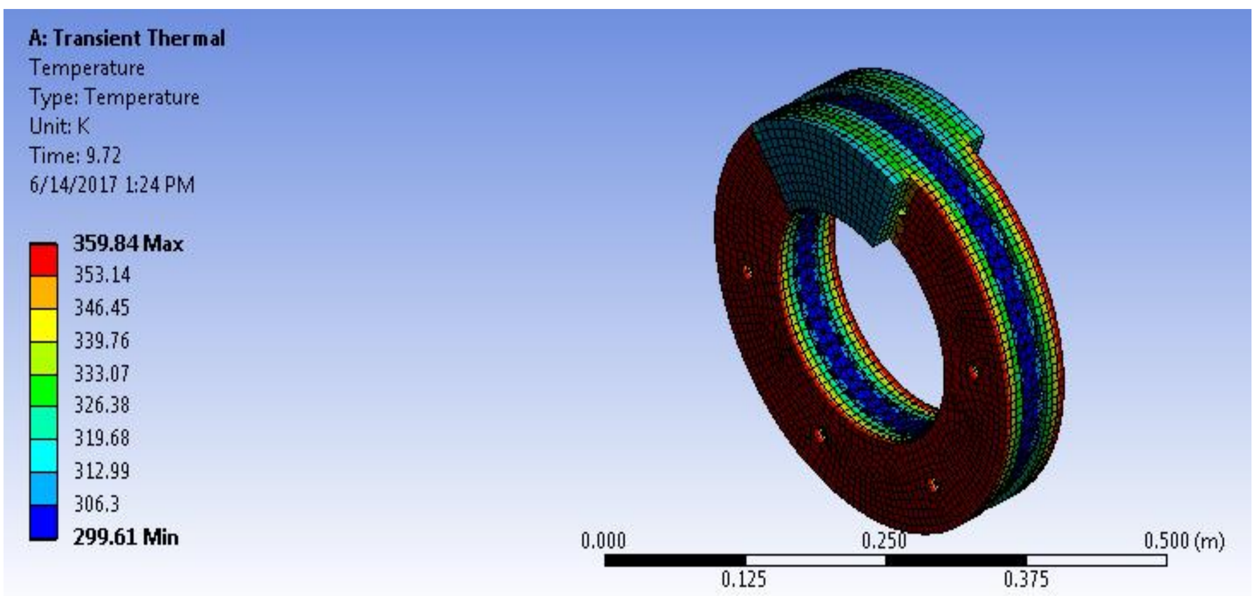


Figure 4.120 M.3.2.a.Temperature of carbon-carbon composite.

The maximum temperature of carbon-carbon composite of this model 3 is less than the one of model 1 and model 2.

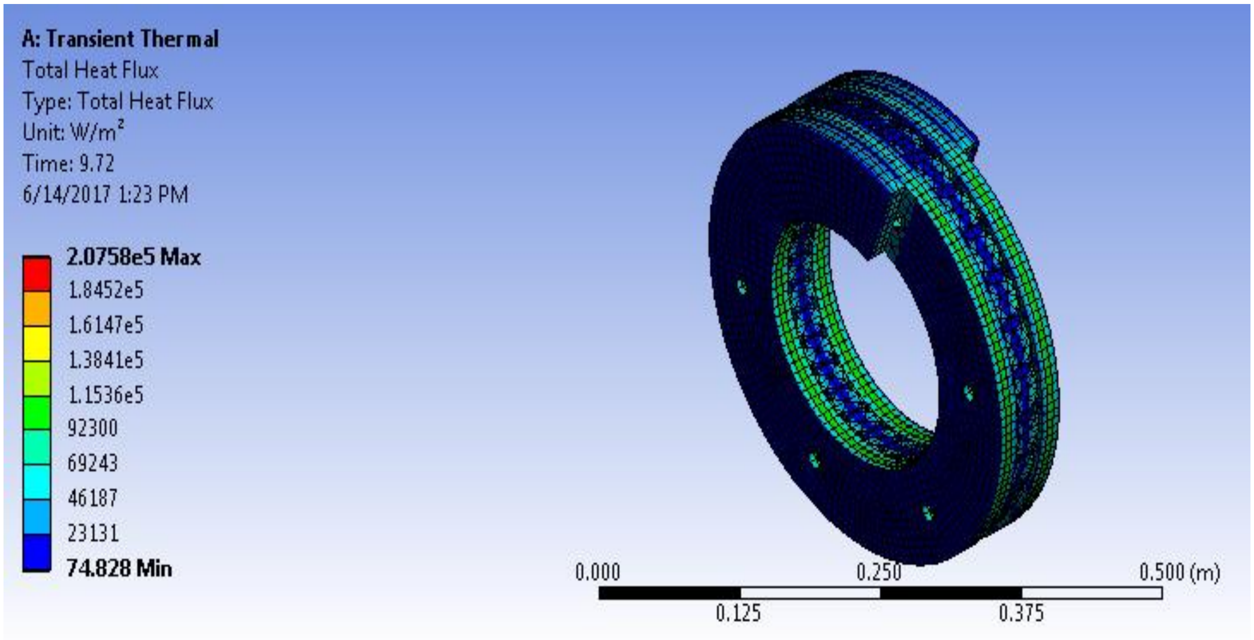


Figure 4.21 M.3.2.b. total heat flux of carbon-carbon composite.

The maximum heat flux for this model 3 is less than the heat flux for 2 other models.

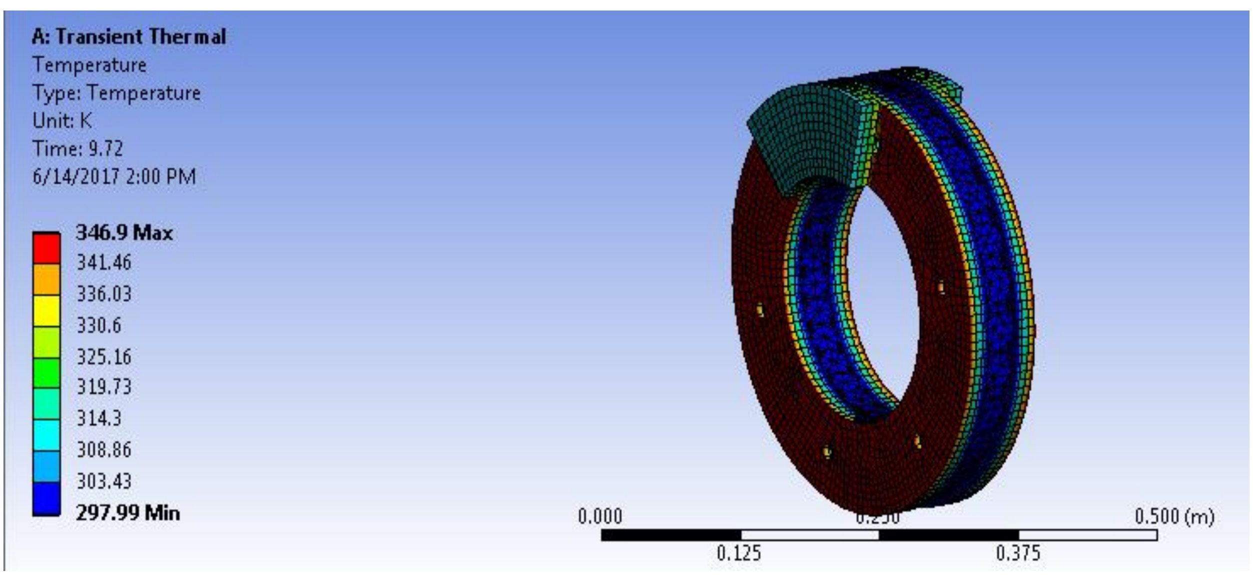


Figure 4.22 M 3.3.a. Temperature of SiC/AL7075 composite.

The maximum temperature of SiC/AL7075 composite for model 3 is smaller than the maximum temperature of model 1 and model 2.

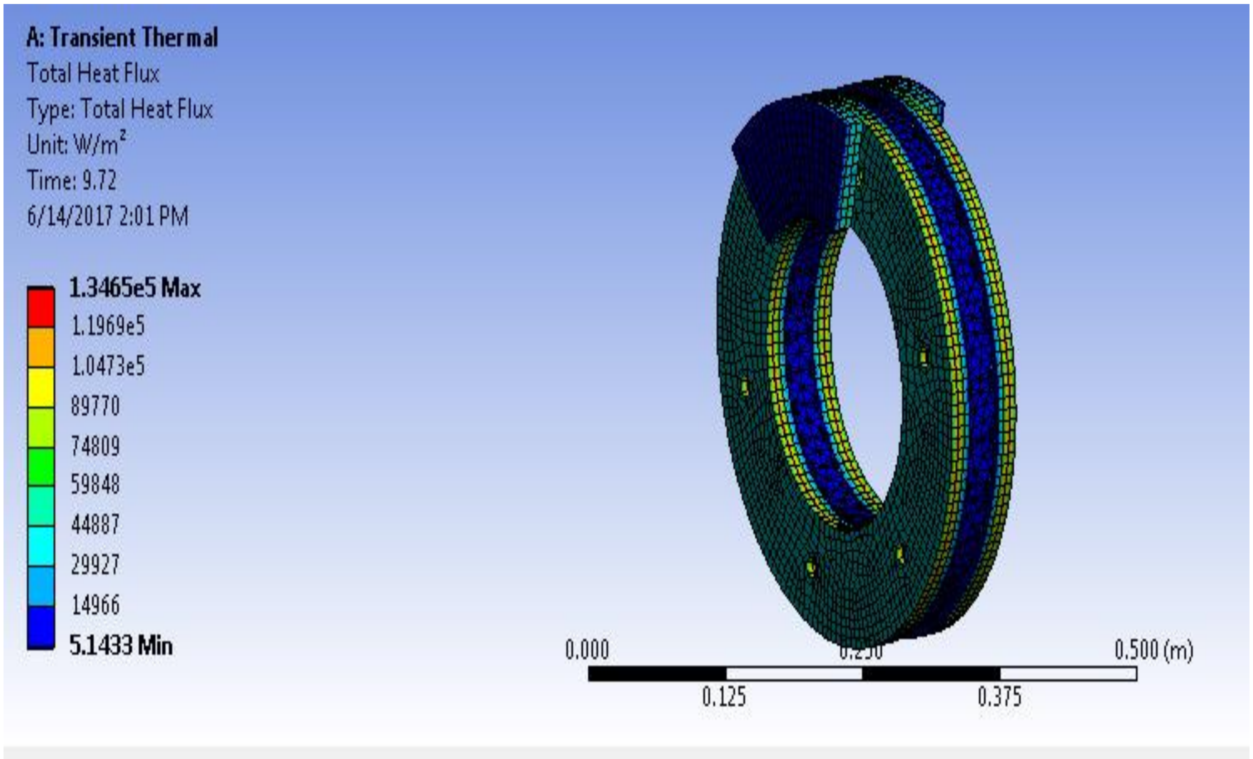


Figure 4.23 M 3.3.b. total heat flux of SiC/AL7075 composite.

This figure shows the distribution of heat flux for SiC/AL7075 composite for model 3.

Table 9: Thermal Analysis Results

Different materials	Different models	Temperature (K)		Total heat flux(w/m^2)	
		Minimum	Maximum	Minimum	Maximum
Cast iron	Model 1 r = 170mm Thick=50mm	310.71	389.31	385.74	5.871e5
	Model 2 r = 180mm Thick=60mm	303.71	368.07	182.08	4.0163e5
	Model 3 r = 190mm Thick=70mm	300.59	353.12	169.4	2.616e5
Carbon-carbon composite	Model 1 r = 170mm Thickness =50mm	307.19	379.71	416.28	5.2795e5
	Model 2 r = 180mm Thickness =60mm	301.81	375.1	335.29	3.4358e5
	Model 3 r = 190mm Thickness =70mm	299.61	359.84	74.828	2.0758e5
SiC/Al7075 composite	Model 1 r = 170mm Thickness =50mm	298.34	367.61	23.129	2.0771e5
	Model 2 r = 180mm Thickness =60mm	298.56	353.59	89.681	1.9915e5
	Model 3 r = 190mm Thickness =70mm	297.99	346.9	5.1433	1.3465e5

4.6.2. Structure Analysis Results

For model 1

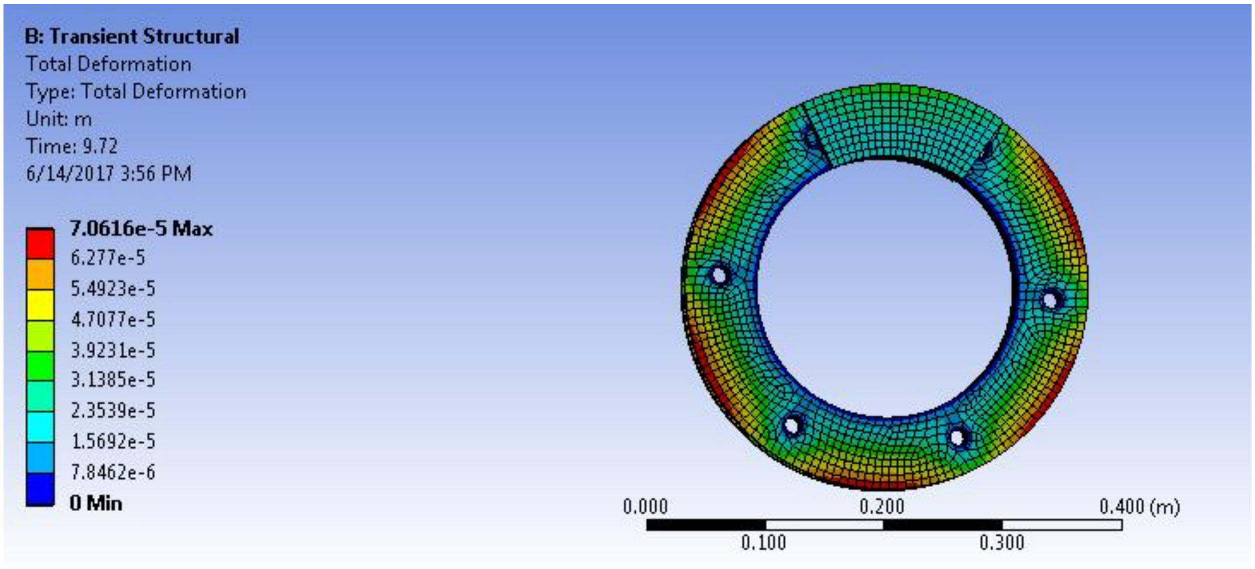


Figure 4.24 M 1.1.a. Deformation of cast iron.

This figure shows as the deformation cast iron for model 1 which is maximum at the corner and minimum at the fix parts.

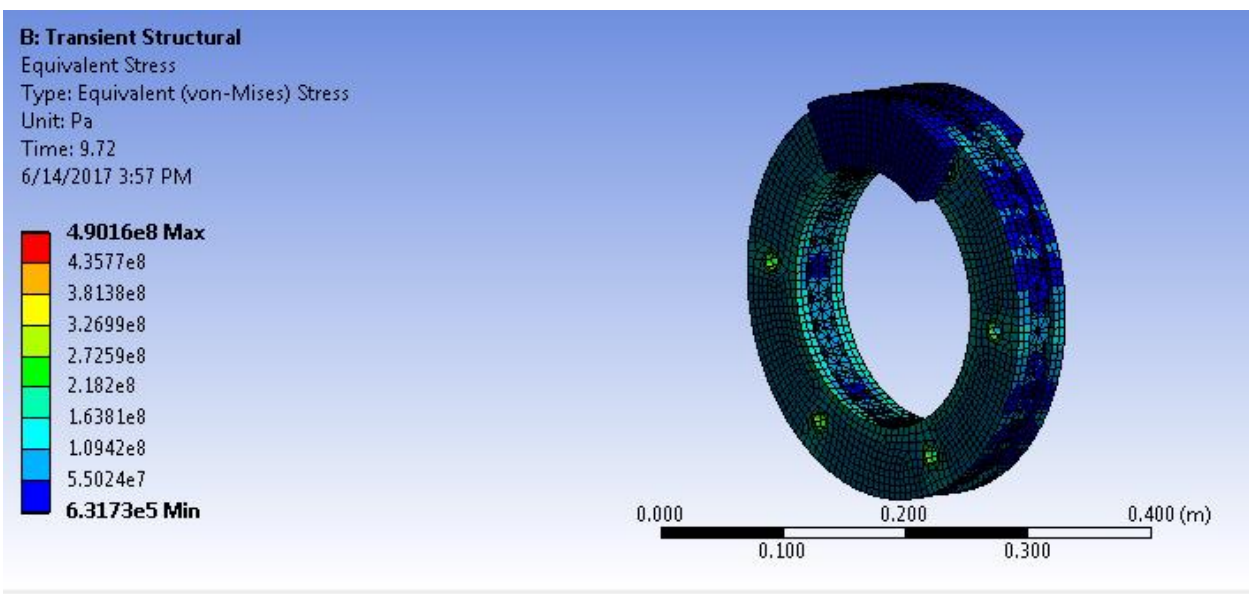


Figure 4.25 M 1.1.b Equivalent stress of cast iron.

This figure shows the distribution of equivalent stress on the disc which is maximum at parts like holes.

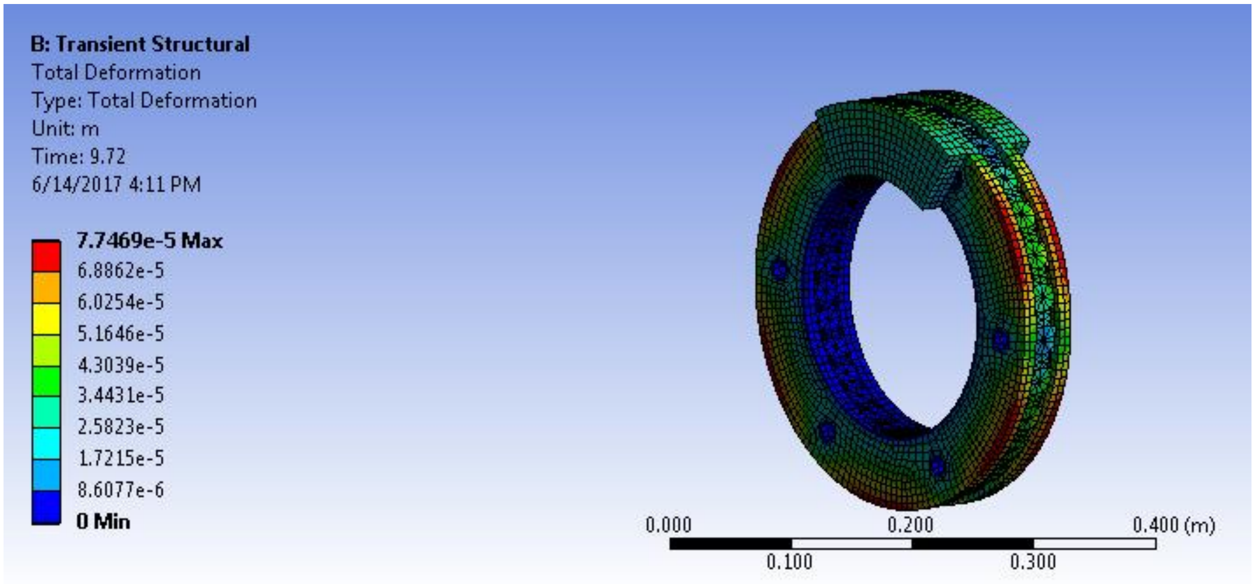


Figure 4.26 M 1.2.a. Deformation of carbon-carbon composite.

This figure shows as the deformation of carbon-carbon composite which is maximum between holes.

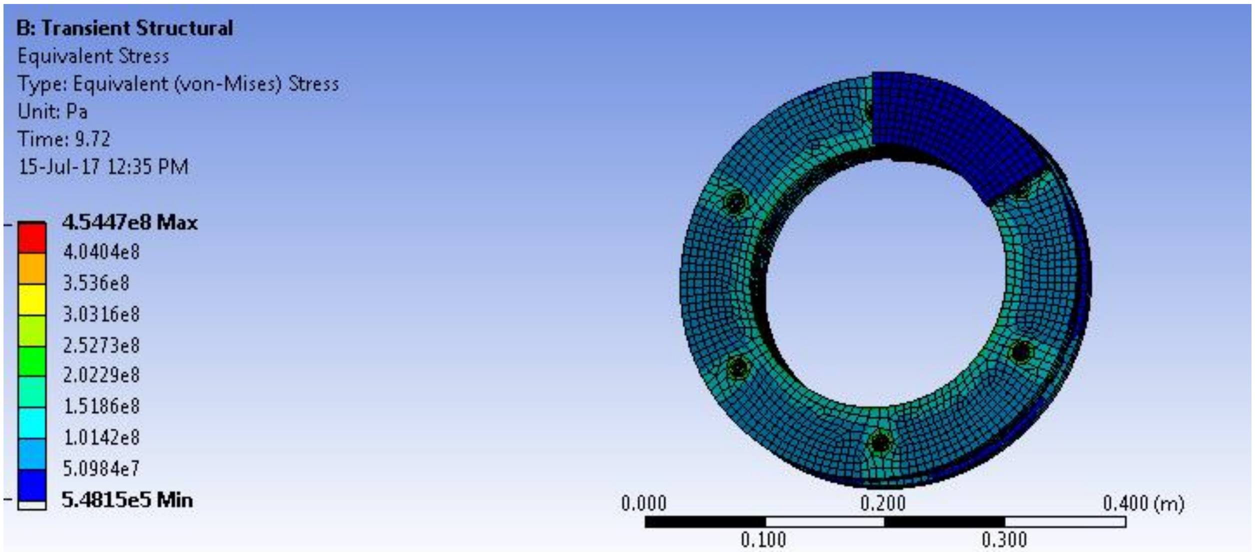


Figure4.27 M.1.2.b. Equivalent stress of carbon-carbon composite.

This figure shows the equivalent stress of carbon-carbon composite which is always maximum at the fixed parts.

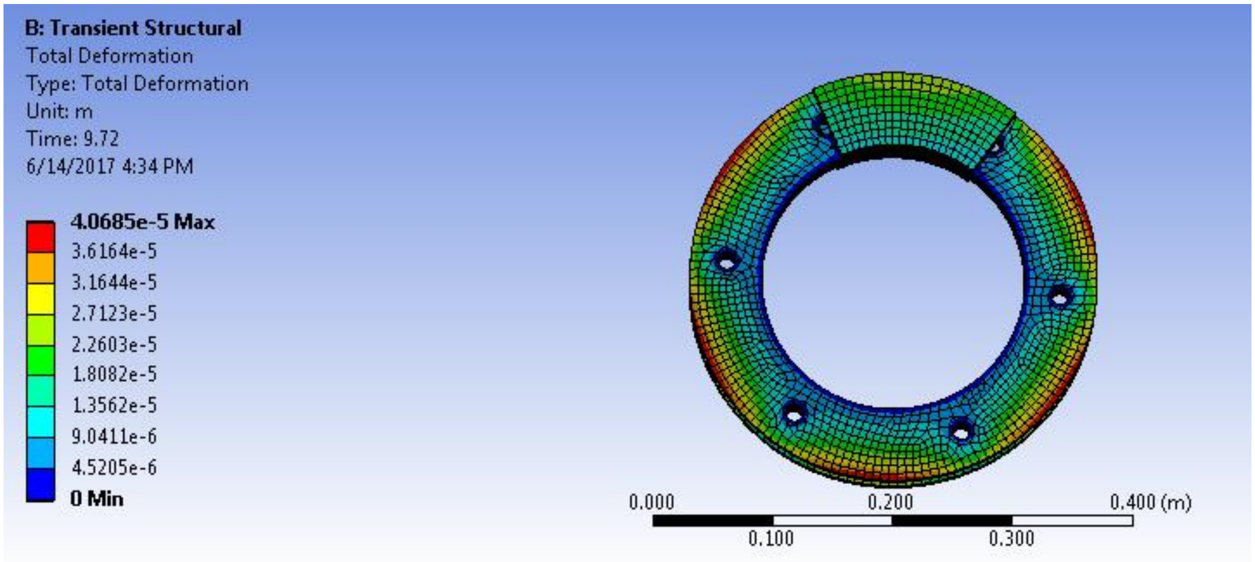


Figure 4.28 M 1.3.a Deformation of SiC/AL7075 composite.

This figure shows the deformation of SiC/AL7075 and this material has the minimum deformation for model 1.

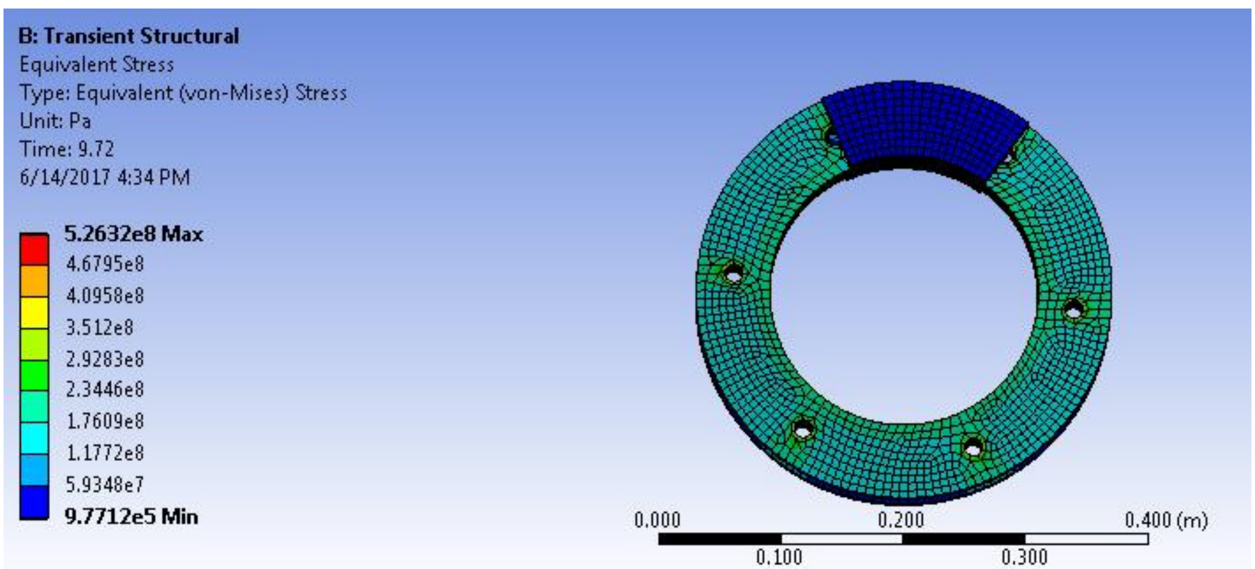


Figure 4.29 M 1.3.b Equivalent stress of SiC/AL7075 composite.

This figure shows the distribution of stress for SiC/SL7075 which is maximum at the fixed contacts.

For model 2

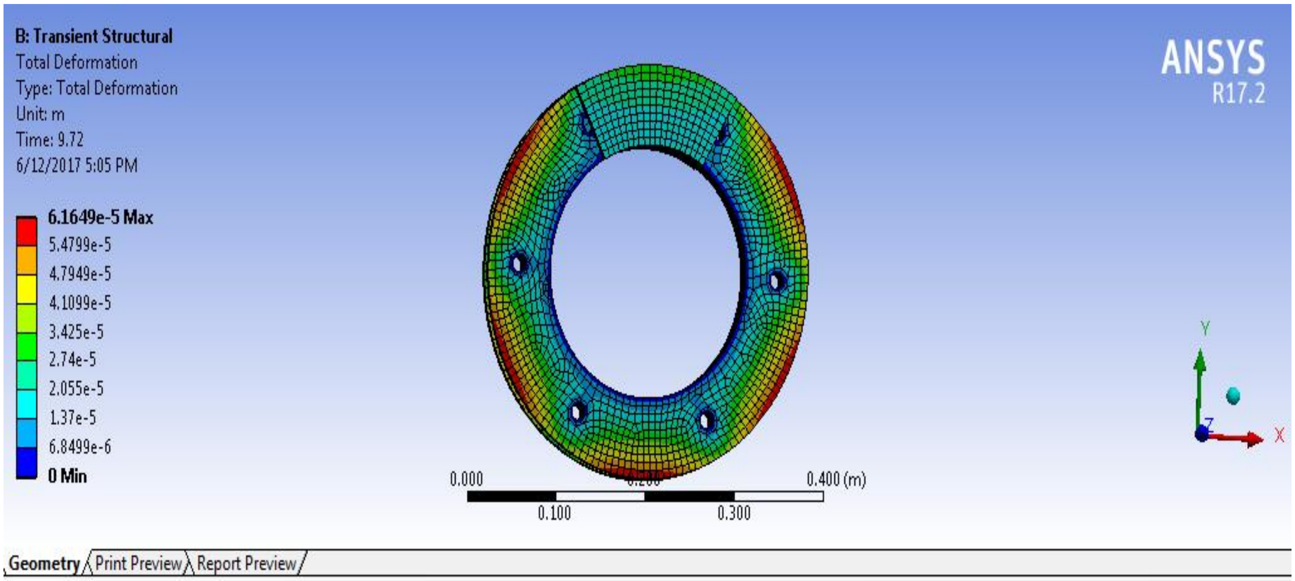


Figure 4.30 M 2.1.a. Deformation of cast iron.

This figure shows the deformation of cast iron for model 2 which is less than one for model 1.

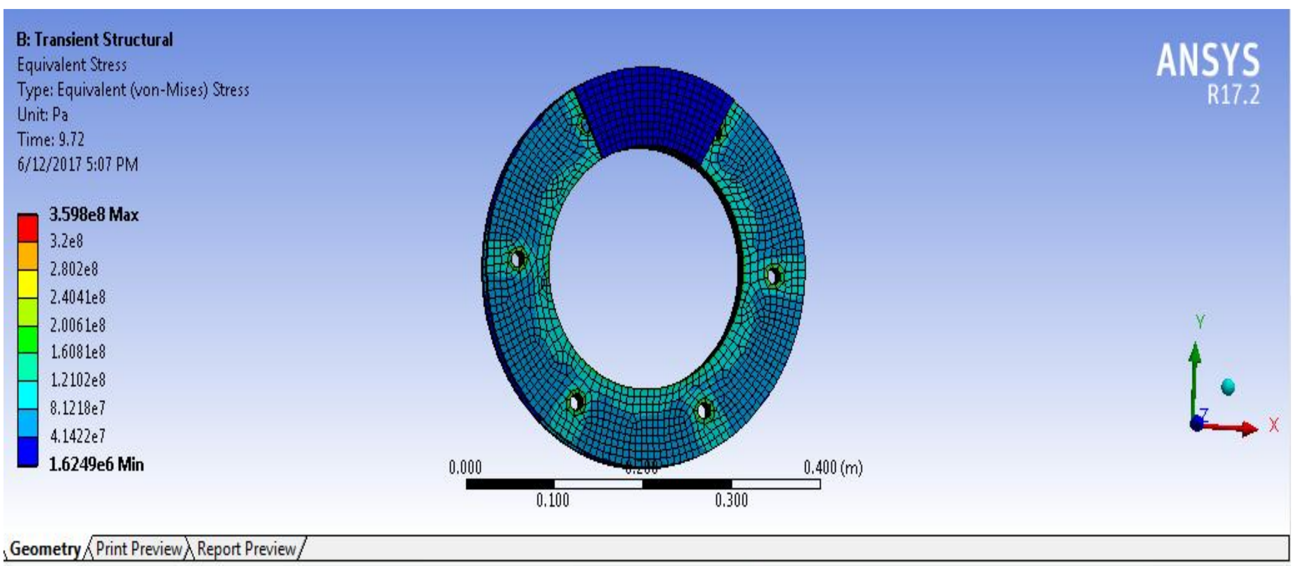


Figure 4.31 M 2.1.b Equivalent stress of cast iron.

This figure shows the equivalent stress of cast iron for model 2 which is less than one for model1.

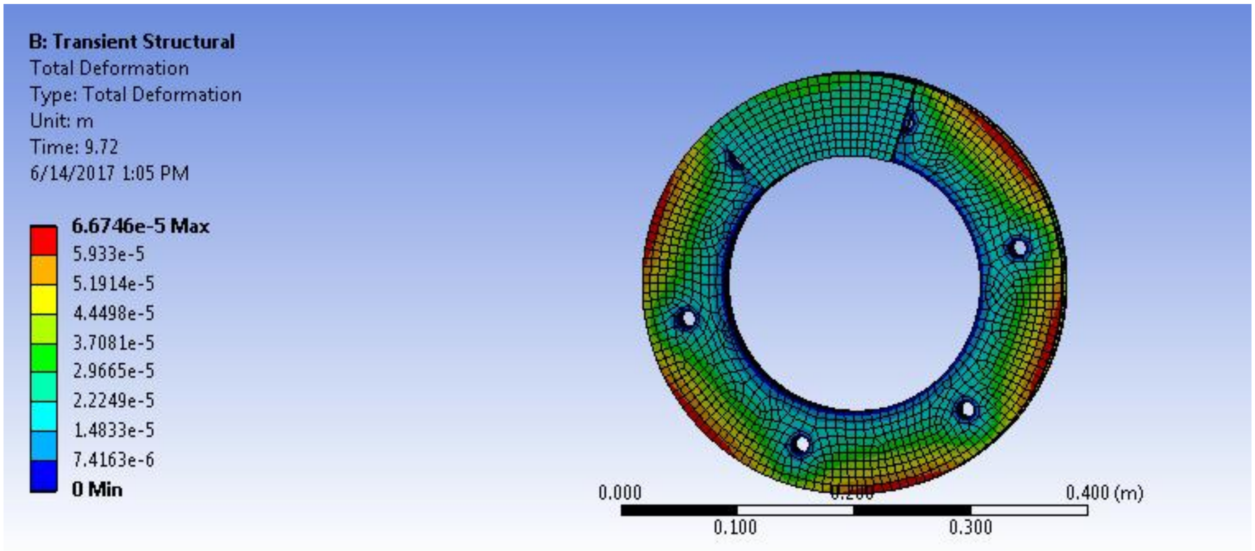


Figure 4.32 M 2.2.a. Deformation of carbon-carbon composite.

This figure shows the deformation of carbon-carbon composite for model 2.

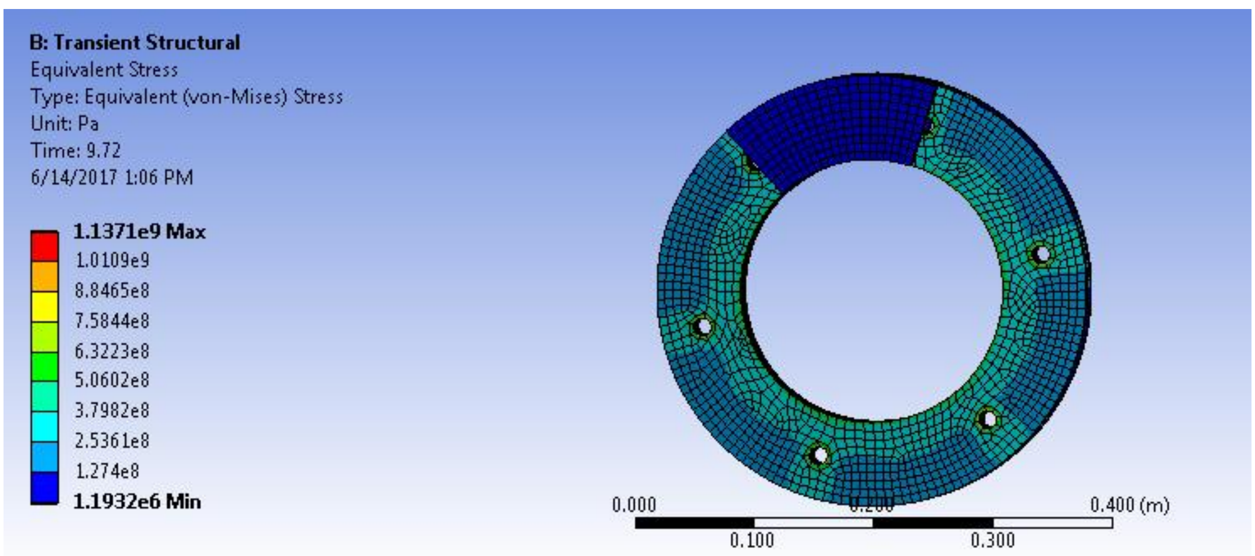


Figure 4.33 M 2.2.b Equivalent stress of carbon-carbon composite.

This figure shows the equivalent stress of carbon-carbon composite for model 2.

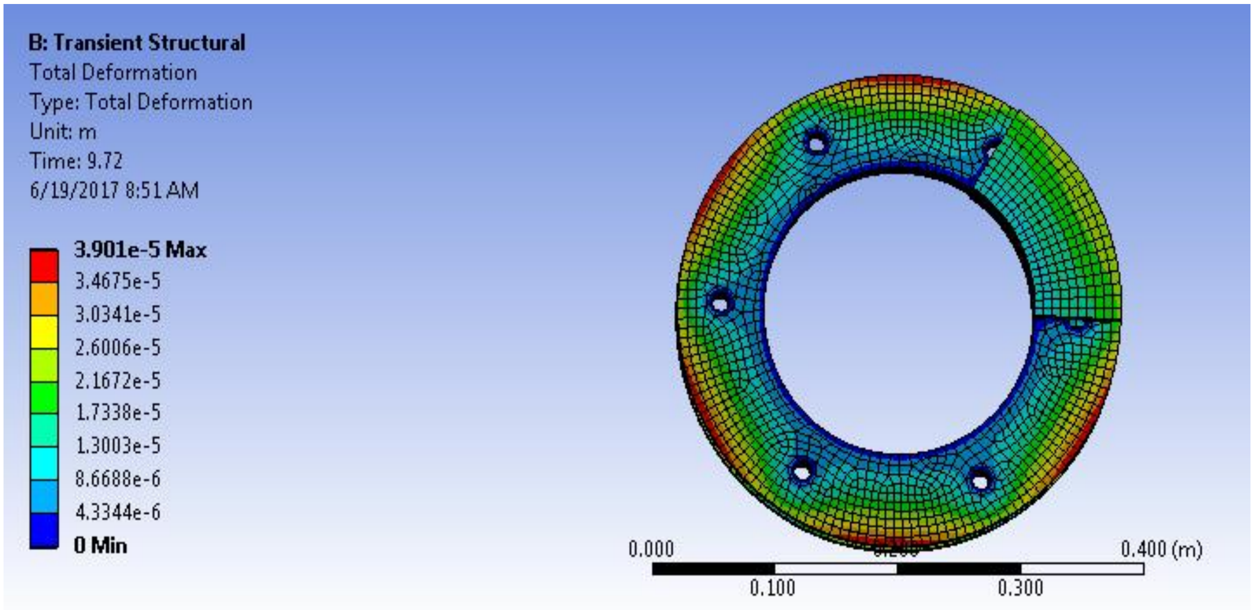


Figure 4.34 M 2.3.a Deformation of SiC/AL7075 composite.

This figure shows the distribution of deformation for SiC/SL7075 which is maximum between holes.

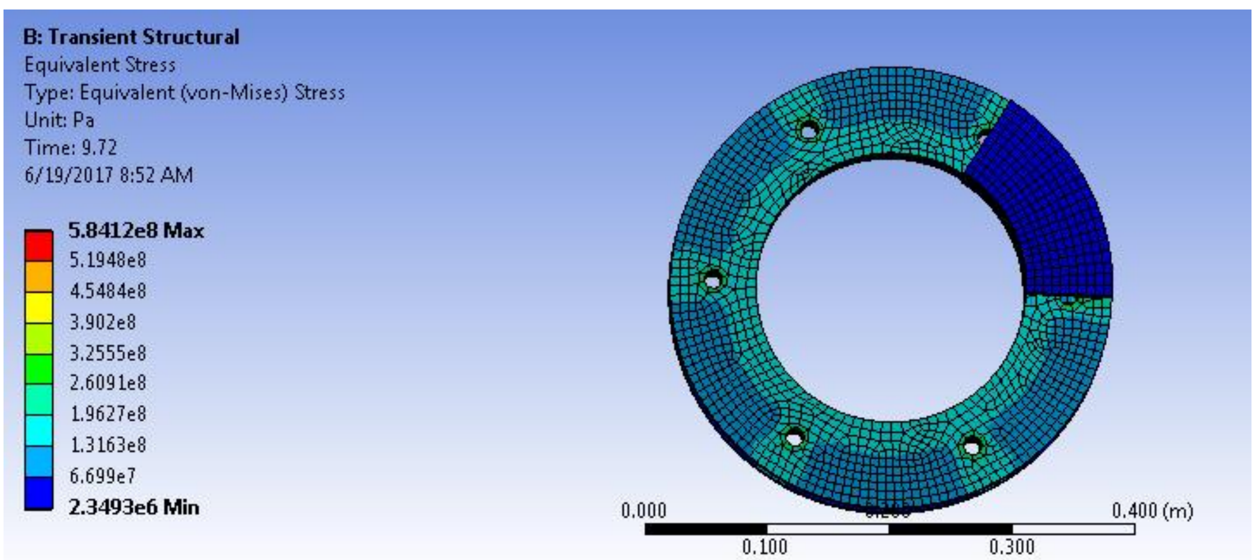


Figure 4.35 M 2.3.b Equivalent stress of SiC/AL7075 composite

This figure shows the distribution of equivalent stress for SiC/SL7075 which is maximum at the fixed contacts.

For model 3

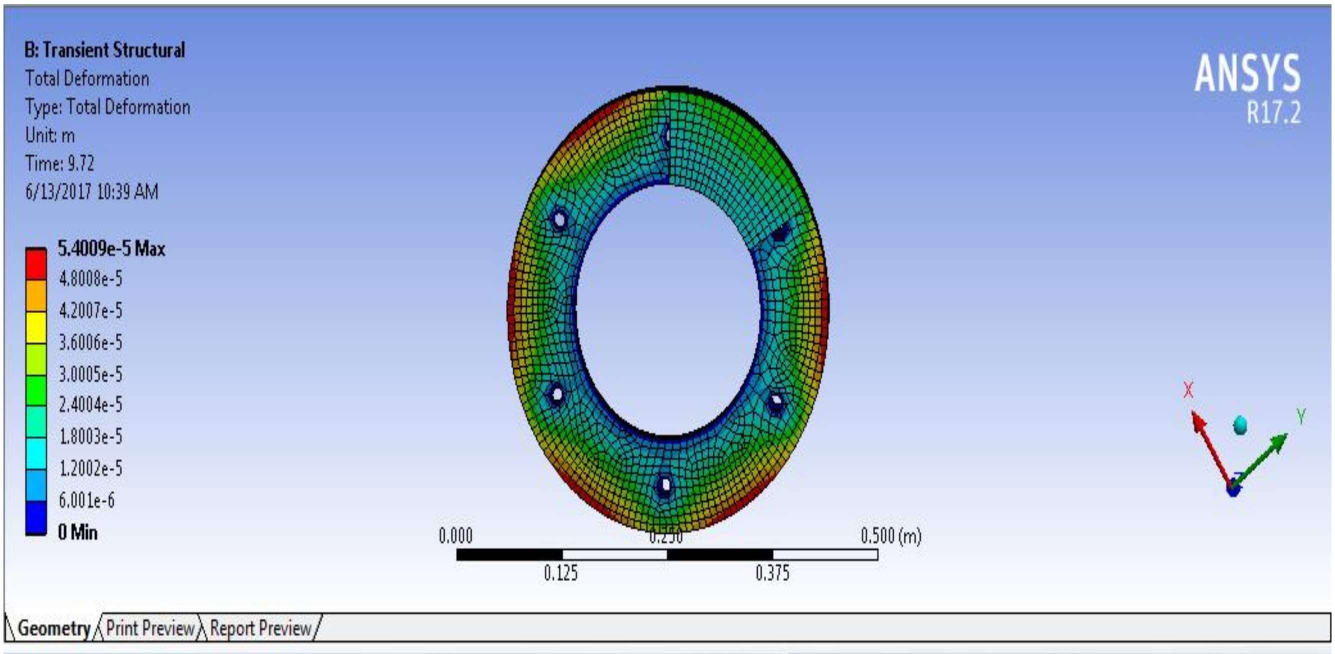


Figure 4.36 M 3.1.a. Deformation of cast iron.

This figure shows the distribution of deformation of cast iron for model 3 which is less than the one for model 1 and model 2.

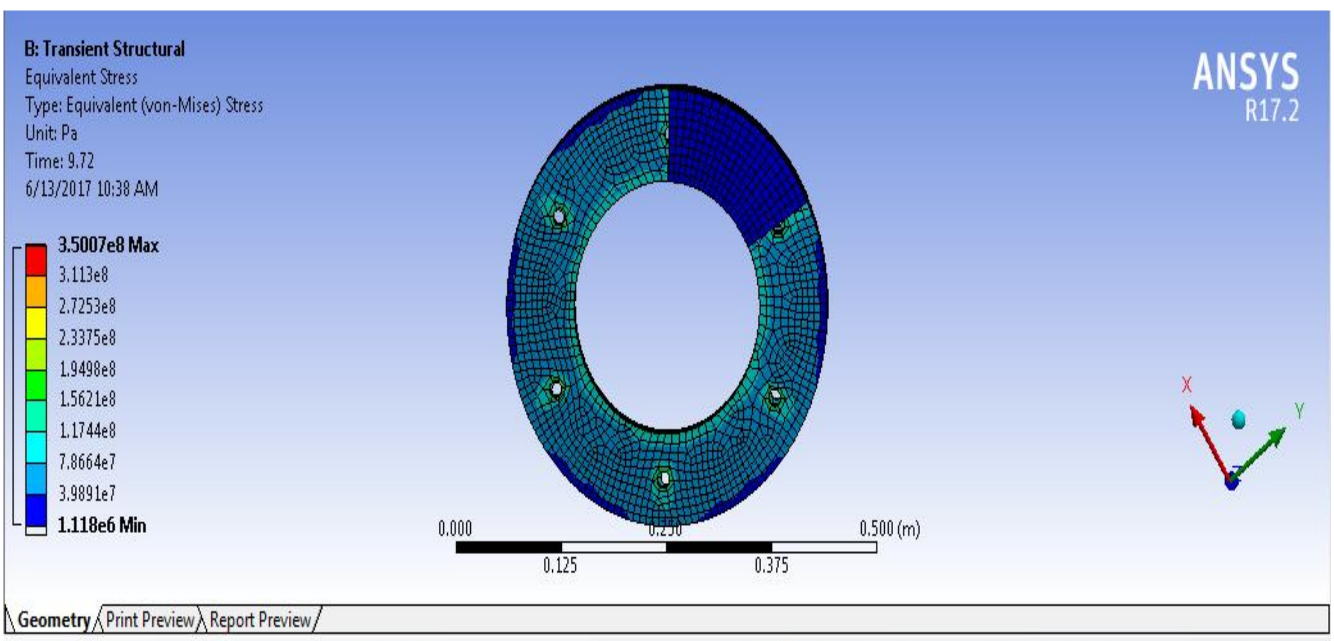


Figure 4.37M 3.1.b Equivalent stress of cast iron.

This figure shows the equivalent stress of cast iron which is maximum at the fixed parts.

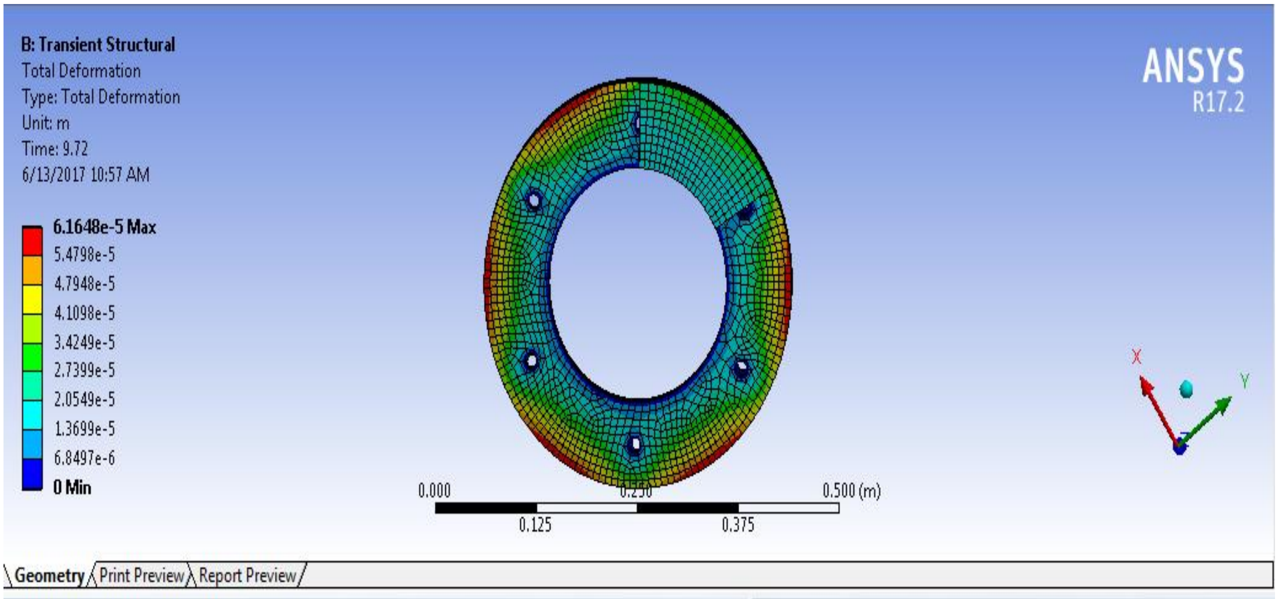


Figure 4.38 M 3.2.a .Deformation of carbon-carbon composite.

This figure shows the deformation of carbon-carbon composite which is maximum far from holes.

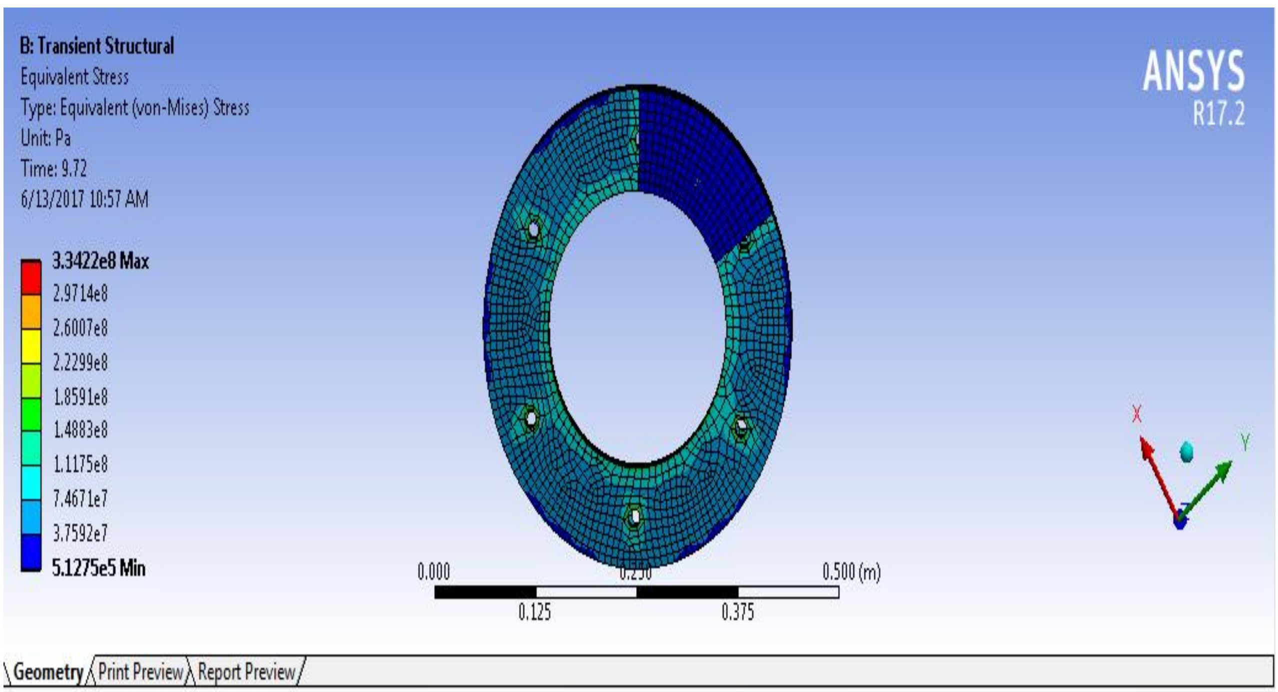


Figure 4.39 M 3.2.b Equivalent stress of carbon-carbon composite.

This figure shows the equivalent stress of carbon-carbon composite for model 3.

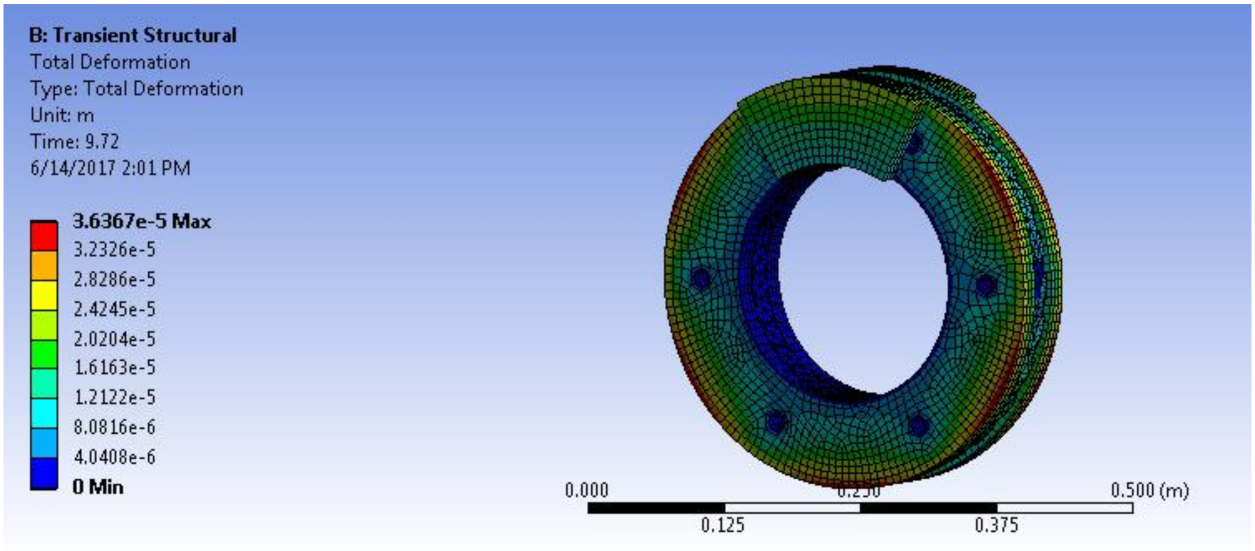


Figure 4.40 M 3.3.a. Deformation of SiC/AL7075 composite.

This model 3 for SiC/AL7075 has the minimum deformation for all models.

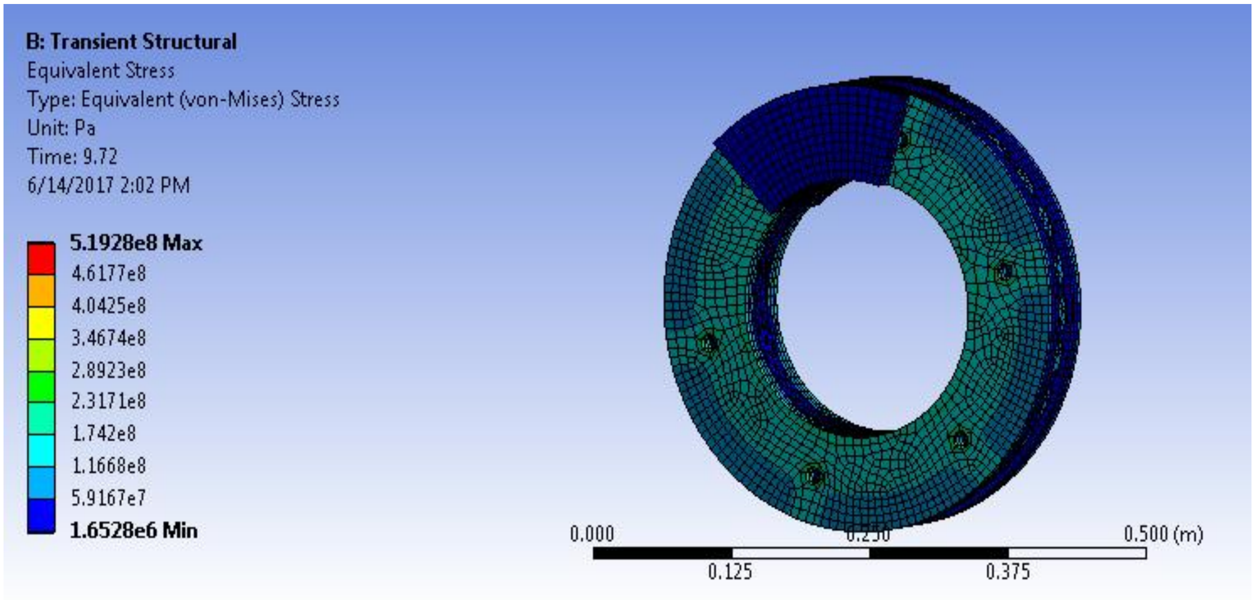


Figure 4.41M 3.3.b Equivalent stress of SiC/AL7075 composite.

This figure shows equivalent stress of SiC/AL7075 for model 3.

Table10. Structural Analysis Results

Different materials	Different models	Equivalent stress(Pa)		Total deformation(m)	
		Minimum	Maximum	Minimum	Maximum
Cast iron	Model 1 r = 170mm Thickness=50mm	6.3173e5	4.9016e8	0	7.0616e-5
	Model 2 r = 180mm Thickness=60mm	1.6249e6	3.598e8	0	6.1649e-5
	Model 3 r = 190mm Thickness=70mm	1.180e6	3.5007e8	0	5.4009e-5
Carbon-carbon composite	Model 1 r = 170mm Thickness=50mm	5.4815e5	4.5447e9	0	7.74469e-5
	Model 2 r = 180mm Thick=60mm	1.1932e6	1.1371e9	0	6.6746e-5
	Model 3 r = 190mm Thickness=70mm	5.1275e5	3.3422e8	0	6.1648e-5
SiC/Al7075 composite	Model 1 r = 170mm Thickness=50mm	9.7712e5	5.2632e8	0	4.0685e-5
	Model 2 r = 180mm Thickness=60mm	2.3493e6	5.2412e8	0	3.901e-5
	Model 3 r = 190mm Thickness=70mm	1.6528e6	5.1928e8	0	3.6367e-5

4.7. DISCUSIONS

From thermal analysis we can see that the temperature and heat flux can change the properties of the materials, so for same material when the radius and thickness of the disc increase the temperature and the heat flux decrease. For example model 1 for cast iron temperature decreases 389.31 to 353.12 (K) and heat flux 5.871e5 to 2.616e5 (w/m2) for cast iron.

The minimum temperature and the heat flux are obtained for aluminium alloy 7075 with silicon carbide SiC /AL7075 which are 346.9(K) and 1.3465e5w/m^2 respectively

From the structure analysis the figures show the results for different materials and models. For model 2 which has the dimension used in AALRT with r = 180mm and thickness= 60mm. The material which has the minimum deformation is SiC/AL7075 composite with 3.901e-5m and the one which has the minimum equivalent stress is cast iron with 3.598e5Pa. For all the materials the aluminium alloy with silicon carbide SiC/AL7075 has the minimum deformation.

In the summary table we can see also for the same materials changing only the model or shape of disc brake has effect on the stress and the deformation, when we increase the radius and the thickness of the model the stress and deformation will decrease. For cast iron in different models the deformation varies from 7.0616e-5 to 5.4009e-5 m and the stress vary from 4.9016e8 to 3.5007e8 Pa.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORK

5.1 CONCLUSIONS

This thesis is based on the optimization of disc brake using different materials and different radius and thickness to suggest the better model and the optimum material for the disc brake to be used in AALRT in the future. The disc and pad are modelled in the CATIA software and the analysis is done by ANSYS software workbench.

This research does the comparison of different materials which are used for disc brake to see the relationship between the heat generated, temperature raise when braking is applied and the properties of different materials like deformation and stress. When we look at the summary table for temperature and heat flux for different materials and models for one material we can see the relationship between the material and different models and also for one model at different materials. The minimum of deformation is obtain from the figure M 3.3.a which is corresponding the model3 3.636e-5m for SiC/AL7075 and the minimum equivalent stress from the figure M 3.1.b 3.5007e8 for cast iron. Based on the figures above and the table we can conclude that the shape and materials have consequence on the temperature, deformation and stress values.

So after this hole analysis we conclude that the optimum material is the aluminium alloy with silicon carbide SiC/AL7075 and the optimum model is the one designed with radius r=190mm and thickness=70mm.

5.2 RECOMMENDATIONS

For the analysis and results above as the thickness and radius of the disc brake increase the temperature, deformation and equivalent stress decrease and the side of the materials the aluminium alloy with silicon carbide SiC/AL7075 has the minimum temperature and deformation for all the models. So after this analysis the optimum material for disc brake is the aluminium alloy 7075 with silicon carbide SiC/AL7075.

5.3 FURTHER WORK

This thesis was focus on the optimization of the materials for disc brake using different radius and thickness and for different materials. The analysis was done in the ANSYS software workbench.

But for the future the following points may be studied further in the disc brake.

- Validating the result experimentally
- Methods to reduce temperature gradient will be the future study
- Effect of wear between disc an pad using software’s
- Using different materials for the pad

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