

**CRACK PROPOGATION AND J INTEGRAL EVALUATION OF
SURFACE CRACK OF BRAKE ROTAR OF DISC BRAKE.**

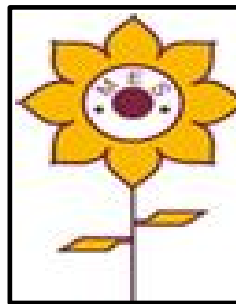
Submitted in partial fulfilment of the requirements
for the degree of
Bachelor of Engineering in Mechanical Engineering

by

Sagar R Kusundal.
Shrikant A Katke.
Sarvesh R Mayekar.

Under the guidance
of

Mr. Suhas Uthale



DEPARTMENT OF MECHANICAL ENGINEERING

Mahatma Education Society's

PILLAI HOC COLLEGE OF ENGINEERING and TECHNOLOGY

Pillai HOCL Educational Campus, Rasayani

Tal: Khalapur, Dist: Raigad-410207

University of Mumbai

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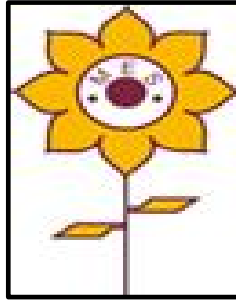
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DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

This is to certify that the project synopsis entitled “**Crack Propagation and J Integral evaluation of surface crack of Brake rotor of Disk brake**” is successfully submitted by following students:

GROUP NO: M07

Sagar R Kusundal 62

Shrikant A Katke 52

Sarvesh R Mayekar 72

As per the syllabus and in partial fulfilment for the completion **Bachelor's degree** in **Mechanical Engineering** from University of Mumbai, it is also to certify that this is the original work of the students done during the academic year 2018-2019.

Project Guide

Head of Department

Principal

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Sagar R Kusundal.

Shrikant A Katke.

Sarvesh R Mayekar.

B.E. Mechanical Engineering

ABSTRACT

Disc Brake is an essential Component of automotive braking system. Its generally subjected to high amount of temperature and pressure for continuous stopping of vehicles. The literature shows most of work is done on the structural strength and transient temperature impact on disc brake. No work is executed on crack development at high stress intensity point on the disc brake surface.

150cc Pulsar two-wheeler is considered for designing and analysis of the disc. 3D Modelling of the disc brake is done by 3D Modelling software Solidworks and All the design parameters are taken from the literature papers. Finite Element analysis software ANSYS workbench 15.0 is used for Structural, Thermal and Crack development analysis at actual working condition of the disc brake.

Finite element analysis on the disc brake shows that, Crack initiation taken place at High intensity point on the crack surface and Crack Development will happen when J Integral value of the Simulation crosses the SIF of the Material. FEA simulation also show the rate at which crack develops and direction of crack Movement.

	Title	Page no.
	List of Figures	8
	List of Tables	9
Chapter 1	Introduction	10
	1.1 Crack in Automotive parts/ Disc Brake	10
	1.2 Causes of cracks in frictional surface	12
	1.2.1 Heat Dissipation	12
	1.2.2 Hot spot generation in disc brakes	13
	1.2.3 Thermal judder	14
	1.2.4 Due to thermal cracking	15
	1.3 Disc Brake	
	1.3.1 Introduction	16
	1.3.2 Types of Disc brake	16
	1.3.3 Fixed caliper	17
	1.3.4 Floating caliper	18
	1.3.5 Terminology for Disc brake	18
	1.3.6 Advantages of floating caliper fixed caliper.	19
	1.3.7 Difference between fixed calliper and floating Caliper disc.	20
Chapter 2	Literature Review	21
Chapter 3	Objective and Problem Definition	
	3.1 Objectives	24
	3.2 Problem Definition	25
Chapter 4	Methodology of the Project.	26

Chapter 5	Vehicle Specification and Theoretical calculation	28
	5.1 Specification of Bajaj Pulsar 160cc two-wheeler Bike.	28
	5.2 Theoretical calculation of Disc brake.	29
Chapter 6	J-Integral & Stress Intensity Factor	30
	6.1 Stress Intensity Factor	
	6.1.1 Introduction	30
	6.1.2 Modes of Crack Failures	31
	6.2 Evaluation of J-Integral	32
	6.3 Relation between J-Integral & K factor	33
Chapter 7	3D Modelling using Solidworks	
	7.1 Modeling of Disc plate using Solidworks.	
	7.1.1 Introduction to SOLIDWORKS	34
	7.2.1 Detail Drawing of Disc Brake	35
	7.2.2 Procedure for 3D modelling using Solidworks	35
Chapter 8	Simulation of Disc brake using FEA	
	8.1 Introduction to FEA	40
	8.2 Procedure in FEA	41
	8.2.1 Pre-processing	
	8.2.2 Solution	
	8.2.3 Post processing	
	8.3 Steps for Static Analysis of Disc brake	42
	8.4 Simulation results of Disc brake	44
	8.4.1 Meshing of the geometry.	
	8.4.2 Fracture	
	8.4.3 Boundary conditions For Steady State Thermal	45
	8.4.4 Boundary conditions For Transient Structural	46
	8.5 Simulation Results for Steady-State Thermal Analysis	46
	8.5.1 Surface Temperature	
	8.5.2 Total Heat Flux	46
	8.6 Simulation Results for Transient Structural Analysis	47
	8.6.1 Equivalent Stresses for disc rotor	
	8.6.2 Total Deformation	
	8.6.3 Fatigue analysis for Life span of system.	
	8.7 Simulation Results for Crack Analysis	49
	8.7.1 Crack 1	

- 8.7.2 Crack 2
- 8.7.3 Crack 3
- 8.7.4 Crack 4
- 8.7.5 Crack 5

Chapter 9	Result and Conclusion	
	9.1 Results	59
	9.2 Conclusion	60

List of Figures

Figure No.	Title	Page no.
1.1	Thermal cracking in disc brakes	11
1.2	Heat Dissipation	13
1.3	Disc brake	16
1.4	Fixed caliper	17
1.5	Floating caliper	18
1.6	Terminology of Disc brake	19
7.2.1	Detailed drawing of Disc Brake model.	35
7.2.2	Working Window of Solidworks 2015	36
7.2.3	Sketch feature is used.	36
7.2.4	Extrude feature is used.	37
7.2.5	Sketch Feature Is Used For Brake Pads.	37
7.2.6	Extrude feature is used for making brake pads	38
7.2.7	CAD Model of Disc Brake with Pads	38
7.2.8	Rendered part of Original Disc brake	39
8.3.1	Homepage of ANSYS Workbench 18.0.	42
8.3.2	Selection of Static Structural from Analysis System	43
8.3.3	Defining Materials in Engineering Data Sources.	43
8.4.1	Mesh for Steady State Thermal	44
8.4.2	Fracture mesh for the Disc Brake rotor	45
8.4.3	Boundary Conditions for Steady State Thermal	45
8.4.4	Boundary Condition for Static Structural	46
8.5.1	Surface Temperature for Disc Brake.	46
8.5.2	Total Heat flux	47
8.5.1	Von mises Stresses for Transient structural	47
8.6.2	Total Deformation for Transient structural	48
8.6.2	Total Life	48
8.7.1	Stress Intensity Factor K1 analysis	49
8.7.2	Stress Intensity Factor K2 analysis	49
8.7.3	Stress Intensity Factor K3 analysis	50
8.7.4	J-Integral Factor analysis	50
8.7.5	Stress Intensity Factor K1 analysis	51
8.7.6	Stress Intensity Factor K2 analysis	51
8.7.7	Stress Intensity Factor K3 analysis	52
8.7.8	J-Integral Factor analysis	52
8.7.9	Stress Intensity Factor K1 analysis	53
8.7.10	Stress Intensity Factor K2 analysis	53
8.7.11	Stress Intensity Factor K3 analysis	54
8.7.12	J-Integral Factor analysis	54
8.7.13	Stress Intensity Factor K1 analysis	55
8.7.14	Stress Intensity Factor K2 analysis	55
8.7.15	Stress Intensity Factor K3 analysis	56
8.7.16	J-Integral Factor analysis	56
8.7.17	Stress Intensity Factor K1 analysis	57
8.7.18	Stress Intensity Factor K2 analysis	57
8.7.19	Stress Intensity Factor K3 analysis	58
8.7.20	J-Integral Factor analysis	58

List of Tables

Table No.	Title	Page no.
9.1	FEA Results	59

Chapter 1

Introduction

1.1 Crack in Automotive Parts/ Disc Brake

Thermal cracking is commonly observed in disc brake rotors following high braking events. The cracks fall into two broad categories: a series of heat cracks that partially penetrate the surface of the discs and thru-cracks that completely pass through the disc wall. Though it is well known that thermal cracks do arise from hard braking, there is no formal treatment of the problem of thru-cracks. A failure analysis of thermal cracking in disc brake rotor is done. The analysis was motivated by thermal cracking in the front disc brakes in a pulsar 150cc disc brake. The front brakes failed while the truck was hauling a trailer filled with cattle. Failure occurred after several stops, and was indicated by an audible ping and a pronounced ticking sound during subsequent braking.

Disc brakes are fabricated from grey cast iron with the typical geometry shown in Grey cast iron is chosen for its relatively high thermal conductivity, high thermal diffusivity and low cost. The brake rotor consists of a hat, or hub, which is connected to the wheel and axle, and an

inboard and outboard braking surface. The outboard braking surface is attached directly to the hat, while the inboard braking surface is attached to the outboard unit by a series of cooling vanes. A small groove is machined around the periphery of the hat-rotor attachment site to relieve the stress concentration associated with the change in section. It is important to note that the inboard disc is not directly attached to the hat; its only attachment to the hat is through the cooling vanes. The inboard and outboard rotors are squeezed by the brake pads during braking.

The subsequent frictional work arrests the rotation of the wheel and generates a substantial amount of heat. Braking events last on the order of seconds, generating frictional heating in the rotors while leaving the hat very near room temperature. Thermal cracking is not common in passenger vehicles but it *is* relatively common in trucks and emergency vehicles; the very sorts of vehicles that are exposed to extreme conditions. It is important to note that those conditions are not considered abusive; rather they simply expose the limitations of braking technology. Though the present article was motivated by failure of disc brakes on a truck, the following sections present a general treatment of the problem that is applicable to any vehicle.



Fig.1.1.1 Thermal Cracking in Disc Brakes

1.2 Causes Of Cracks In Frictional Surface

1.2.1 Heat Dissipation

When brake pads and rotor are physically in contact with each other friction is created between them and it results in the generation of heat. In normal braking, the amount of pressure generated in calliper piston is very less; therefore the amount of heat generated is less. So the performance of the disc brake is not severely hampered nor is there any significant reduction in disc's life. But when the sudden or hard braking force is applied, friction between pad and disc increases in order to stop the vehicle. This generates a large amount of heat between disc and pad. When the amount of generation of heat increases, it affects the performance of the braking system. So, dissipation of generated heat is important for the proper working of the braking system Heat is dissipated from the surface in three modes of heat transfer such as convection, conduction, and radiation.

Conduction is heat transfer mode in which heat is transferred through a solid. In the case of the disc brake, conduction takes place from disc to the hub and also through pads. Hub can be an extended portion of the disc or an entirely separate component, with comparatively smaller diameter but larger thickness while pads are packed with a composite material having a high coefficient of friction and are actually responsible for stopping the vehicle. Conductive heat transfers totally depending on the thermal conductivity of a material and area normal to heat flow in case of 1D analysis. As thermal conductivity is different for different materials, heat transfer rate depends on the material of disc brake.

In convection, heat is transferred between the solid surface and a fluid layer adjacent to the solid surface via conduction and then the heat flows through the fluid medium via convection. In the case of the disc brake, the air flowing over surface dissipates heat and reduces the temperature of the disc.

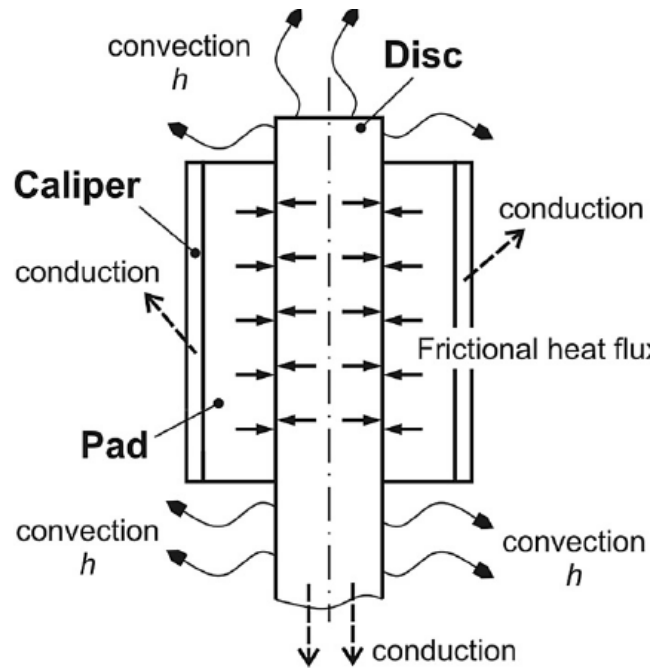


Fig 1.2.1 Heat Dissipation

1.2.2 Hot Spots Generation In Disc Brakes

Developments in vehicle chassis along with the engines have also led to the development of the braking system. To provide adequate braking force the disc and pad as a friction pair operate at temperatures up to 3000C, interface pressures up to 5MPa and rubbing speeds up to 22m/s. Under some conditions an automotive distorts thermally, which leads to the visual evidence of hot spotting, thus creating problems of rotor cracking and judder. Thermal analysis may reveal one notable cause of the presence of hotspots at regular intervals on the rotor. Thermal imaging measurements reveal that heat generation is restricted narrow bands, representing the presence of a localized pressure distribution.

Temperature developed near hotspots is too high about 5000 C. These rapid fluctuations in temperature, of about thermal gradient 3000 C to 6000 C lead to permanent phase change from pearlite to martensite. It could also lead to distortion and variation in disc thickness due to the volume of martensite being higher than pearlite. Near the hotspots due to high-temperature circumferential stresses also known as hoop stresses are developed in bands type patterns. They can be accounted for crack generation and propagation in the rotor.

1.2.3 Thermal Judder

Thermal Judders have forced vibration generated on the brake disc. As the thickness of the rotor varies it leads to physical interference between the rotor and pads while passing over the brake lining which causes variation of the normal forces between the rotor and brake. The stack of vehicle and brake part deforms to allow that interference to pass through the brake, and internal forces and moments vary accordingly. The frequency is consequently directly proportional to the wheel speed and therefore also to the forward velocity of the vehicle. It is thus usual to relate judder frequencies to wheel speed. The frequency of judder which is thermally excited has frequencies of typically 6 to 20 cycles per revolution. Low-frequency vibrations are transmitted from the disc brake to the body as body shake and steering shake, and are audible, causing discomfort to both driver and passengers. As the low frequencies are involved, they are practically felt rather than being audible. At the vehicle design stage, it is important to approach a situation where the brake and the other adjacent components do not have a critical natural frequency or harmonic corresponding with the operational frequencies generated by disc thickness variation or unstable thermal deformation. Judders are also classified as Hot Judders and Cold Judder. Some of the common causes of judder are:

➤ Uneven Wear

Off brake wear, sometimes called ‘cold erosion’, is coupled to disc thickness variation and can lead to ‘cold judder’. Brake discs can develop the variation in thickness as the brake pads in the off-brake mode lightly touch the rotors in some parts but not at all in few others of them thus resulting in non-uniform wear. The off-brake wear may be caused by disc run-out and can be reduced by increasing the distance that the calliper piston is retarded after application of the brake that is the rollback.

➤ Uneven Heating

Thermal deformation of a disc consists of the following:

- Waving or warping of the disc.
- Uneven thermal expansion
- Transformation of phase
- Deposition of heated pre-material on disc

With the increase in radius frictional heat and rubbing speed increases. This may lead to the formation of hotspots.

➤ **External Forces**

Unbalanced and variation in tyre force may induce a tumbling rigid body motion of the disc, because of elasticity of the wheel hub and bearing unit. Such dynamic deflections cause the same type of vibrations as geometrical irregularities. Thus, they may contribute to judder. The wheel hub–bearing design and stiffness contribute to the magnitude of the disc deviation.

➤ **Time-Scales**

Brake judder depends strongly on the braking history, on the short as well as on the long time-scale. There are different three time-scales involved in brake judder:

- Revolution time of wheel
- Brake application time or the time between two braking
- Lifetime of brake components.

➤ **Uneven Friction Films**

The third body layer, friction film is of few micrometers thick consisting of material produced by attrition. The ferrous particles produced by the wear of the cast-iron disc are transformed and oxidized by the atmospheric oxygen and deposited as a grey-black layer on the braking surface of the disc. This layer, together with the corresponding layers on the pads, determines the frictional behavior of the brake. When hot brakes are applied on a stationary vehicle, the pads can adhere to the rotor.

At very high temperatures of almost above 500C, the melted friction material can be burnt into the disc.

1.2.4 Due to thermal cracking

Disc brakes are exposed to large thermal stresses during normal braking and very high thermal stresses during sudden and hard braking. Typical passenger vehicles generate almost as high as 900 0C temperature in a fraction of a second. The possible outcomes of high-temperature excursions are: Surface cracks developed due to thermal stresses; and/or large amounts of plastic

deformation in the brake rotor. In the absence of thermal shock, a relatively small number of high braking cycles are found to generate macroscopic cracks running through the rotor thickness and along the radius of the disc brake

1.3 Disc Brake

1.3.1 Introduction

A disc brake is a type of brake that uses callipers to squeeze pairs of pads against a or "rotor" to create friction. This action retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. Disc brakes utilize callipers, brake rotors and brake pads. Each disc brake has a brake pad on both sides that push against the brake rotor when the driver applies pressure to the brake pedal. Disc brakes offer the best stopping power as disc brakes are commonly used by high performance cars.

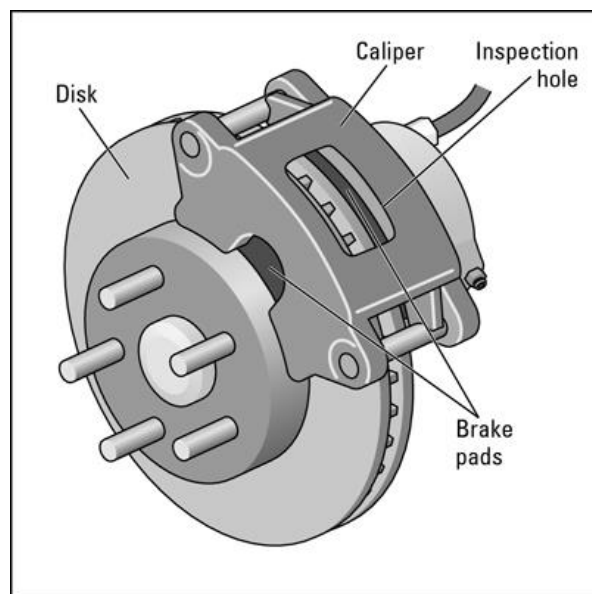
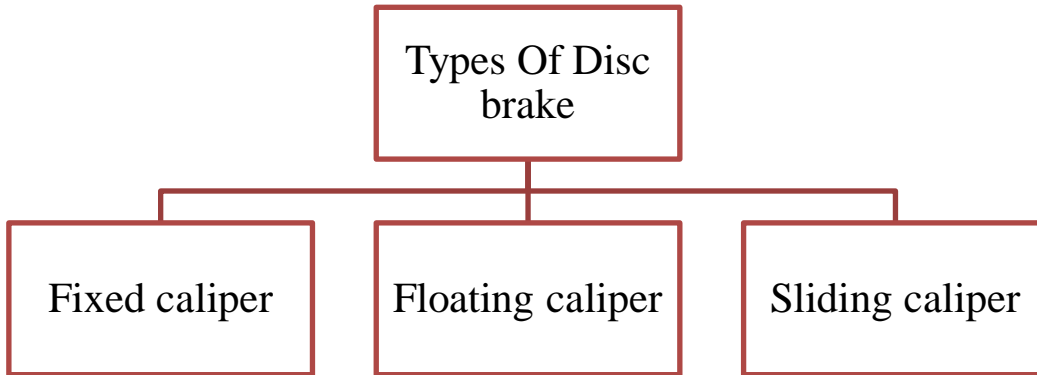


Fig.1.3.1 Disc brake

1.3.2 Types of Disc brake



1.3.2 Fig.

The fixed calliper consists two half callipers (flange and cover), each of which have one or two brake pistons. Both parts, firmly screwed together and connected by the so-called channel bore, make up the fixed calliper. A fixed calliper usually consists of an equal number of pistons on both the inboard and outboard halves of the calliper. When you apply the brakes the pistons on both sides' moves at the same time and squeeze the pads against both sides of the rotor. A fixed calliper is mounted rigid to a bracket or spindle with no sliding pins.

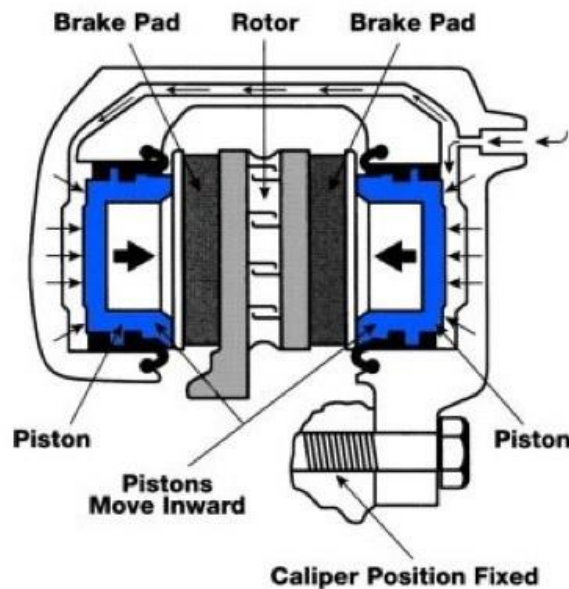


Fig.1.3.3 Fixed Calliper

1.3.4 Floating Calliper

A floating calliper has piston on one side and slides back on pins acting as a clamp. When you apply the brakes, the piston pushes the brake pad on the inboard side against the rotor. The calliper then slides on the pins and squeezes the outboard pad against the rotor. This causes the calliper to clamp" the rotor between the brake pads. With the piston on the inboard side of the calliper it allows better clearance to the wheel as opposed to a fixed mount calliper.

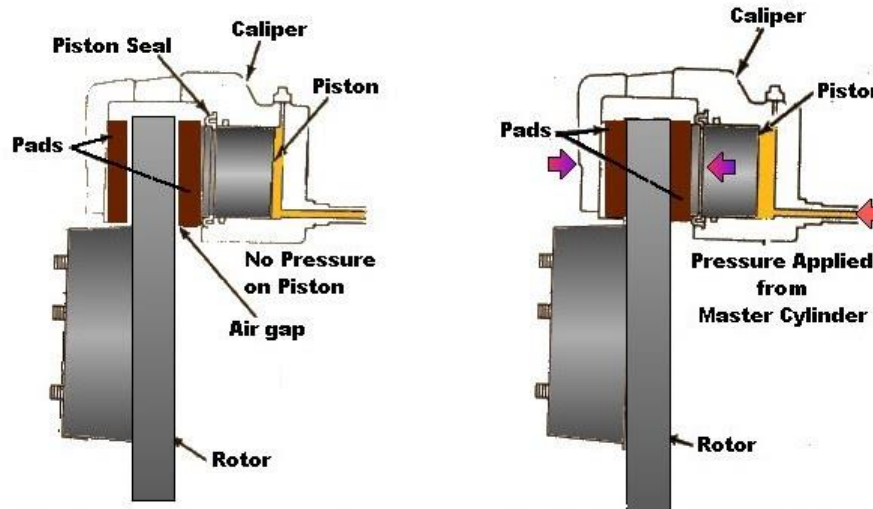


Fig.1.3.4 Floating calliper

1.3.5 Terminology for Disc brake

- **Brake Pads-** There are two brake pads on each calliper. They are constructed of a metal "shoe" with the lining riveted or bonded to it. The pads are mounted in the calliper, one on each side of the rotor.
- **Rotor-** The disk rotor is made of iron with highly machined surfaces where the brake pads contact it. Just as the brake pads wear out over time, the rotor also undergoes some wear, usually in the form of ridges and groves where the brake pad rubs against it. This wear pattern exactly matches the wear pattern of the pads as they seat themselves to the **rotor**.
- **Calliper-** There are two main types of calliper: Floating calliper and fixed calliper. Calliper must be rebuilt or replaced if they show signs of leaking brake fluid. Single Piston Floating Calliper are the most popular and also least costly to manufacture and service. A floating calliper "floats" or moves in a track in its support so that it can

center itself over the rotor, Four Piston Fixed Calliper are mounted rigidly to the support and are not allowed to move. This type of calliper is usually found on more expensive luxury and high performance cars.

- **Piston**-A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings.

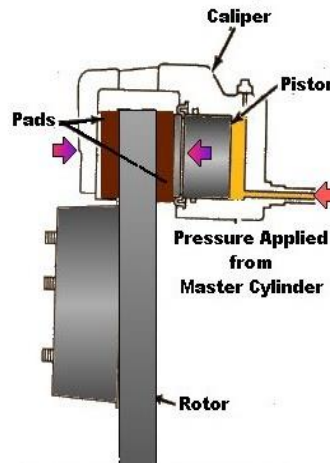


Fig.1.6 Terminology of Disc brake

1.3.6 Advantages of Floating Calliper Brakes over The Fixed Calliper:

- Less fitting space required at the wheel side
- This allows a negative kingpin offset
- No highly stressed screw connections required
- Weight advantage (e.g., only one brake piston)
- Lower temperature generation in the brake fluid due to only one contact surface between piston and brake pad.

1.3.7 Difference between Fixed Calliper and Floating Calliper Disc Brakes

- Fixed calliper disc brakes consist piston both side of disc, whereas floating calliper disc brakes consist piston only one side of the disc.
- Fixed calliper disc brakes are used in high speed racing car, whereas floating calliper disc brakes are generally used with low speed application.
- In the fixed calliper disc brake both pistons move simultaneously when brake is applied, where as in the floating calliper disc brake piston move when brake is applied calliper slide on guide pin.

Chapter 2

Literature Reviews

Comparison of commonly used disc brakes in automotive vehicles viz. Solid and drilled brakes made of gray cast iron are performed. Design and analysis are thoroughly explained and based on proper mechanical calculations; the CAD model is prepared in CATIA V5 software. Steady state Thermal and Structural analysis is performed for both the models by using ANSYS Software and comparison is made for both the models. By comparing the analysis, what concluded is that Ultimate stresses were under the ultimate tensile stress of assumed material i.e. Gray Cast Iron and also that temperature variation and heat flux is slightly lesser for drilled rotor as there is increased in heat dissipation area.[1]

Thermal analysis and optimization for weight reduction of two-wheel vehicles using analytical and numerical modeling of thermal effects during long-term braking for maintaining a constant speed in a downgrade railroad. CAD model of simple brake was prepared and by using ANSYS software topology function, unwanted areas were removed. Hence, a safe thermal stress free and optimized structure is obtained which can further save material cost.[2]

The transient thermal analysis for thermo elastic contact problem of disc brakes by using ANSYS software and thermo elastic behavior of carbon composites are also discussed. By calculations a model was prepared on CATIA software. During the research thermo elastic instability (TIE) phenomenon was observed and its influence on material property is observed. Based on results he found that cast iron is the best material for manufacturing rather than carbon- carbon composite. [3]

The frictional heat generated on the rotor surface during the braking phase, can influence excessive temperature rise which, in turn, leads to undesirable effects such as thermal elastic instability (TEI), premature wear, brake fluid vaporization (BFV) and thermally excited vibrations (TEV). Author tends to reduce these undesirable effects by using better thermal stability materials. CAD model was prepared in Solidworks 2013 and analysis like static structural and thermal was performed in ANSYS Workbench 14.0. For two materials i.e. Gray cast iron and Ti 550. Based on results obtained from analysis, total deformation, von mises stresses and temperature was compared and Ti 550 is suitable with its lesser deformation, stresses and surface temperature than gray cast iron. [4]

Estimation of fatigue crack growth rate considering the J-integral calculations for a semi-elliptical crack for gas turbine compressor blades subjected to centrifugal loading. By using static analysis, crack zone was found out and maximum Von mises stresses were recorded by using ANSYS software. Fractural module was used for evaluation of J- integral in blade with elliptical flaw. Fatigue crack growth rate at the crack length was determined and it was found that fatigue crack growth rate at the surface interception point increases with increase in crack depth and Fatigue crack growth rate at the crack depth increase with the increase in crack length. [5]

Mechanisms of fatigue crack initiation and propagation in CRH EMU brake discs was analyzed in steady as well as braking condition and three kinds of crack propagation was noticed namely, the crackle, radial crack and circumferential crack. A finite element analysis (FEA) was performed to determine temperature and stress distribution in the brake disc as well as to estimate stress distribution during braking. Results indicate more significant residual, circumferential tensile stress on the external friction surface after emergency braking. It is also concluded that when the cracks run along the thickness direction to the specified distance, they cease to run along this direction and begin propagating mainly in the direction of the radius. [6]

Surface crack growth rate by using Energy based J integral method and K factor method in FEA software ABAQUS to study 3-D semi elliptical crack growth in the railway wheel with strain hardening property, subjected to fatigue loading and its comparison. A FEA model of a wheel, with two brake shoes and a portion of rail are created and working condition loads and boundary conditions are applied to the railway wheel model. They concluded that J integral method has more accuracy to calculate of crack growth and also overcome the disadvantages of K factor method. [7]

Stress analysis of an internal crack located at an arbitrary position in a FGM disk with a concentric circular hole with graded material disk assuming the disc to be isotropic with exponentially varying elastic modulus in the radial direction. A comparison was made for different combinations of the crack length, direction, and location with the different materials. The critical values of stress intensity factors and their position in homogeneous and FGM disks are obtained and found that as large are the cracks; the larger is the stress intensity factors. [8]

Failures caused in disc brakes of bicycles and automotive vehicles due to overheating, hotspots generation, thermal judders phenomenon occurring on the disc and crack induced was studied. During their study they found out that a large amount of heat is generated due to sudden braking in fraction of second and because of which thermal stresses are induced which leads to surface cracks and deformation in brake material. They concluded that for reduction in failures, a proper material should be selected with proper ventilation which increases airflow and improves convection rate of disc. [9]

Chapter 3

Objective and Problem Definition

3.1 Objectives

- To study the behavior of the crack on the brake rotor geometry and determine multiple factors to evaluate the life cycle and fracture toughness of the product
- To determine the Stress Intensity Factor (K), Crack Propagation Factor (C), and J Integral of the Crack on the brake rotor geometry with designated material.
- To develop a model with considerable K factor and J Integral to minimize crack growth and crack propagation.

3.2 Problem Definition

The brake system generates necessary force to slow the car, both for racing and emerging situations. The system must be able to easily dissipate heat and handle the energy dissipated by braking without compromising the safety or performance of the car. Failure of disc brake due to the application of the pressure on the brake, it causes to increase its temperature up to 900C for certain interval due to this Thermal Stresses is induced in the system. Due to these thermal stresses there is sudden expansion and contraction which points to system failures and inefficient braking.

Chapter 4

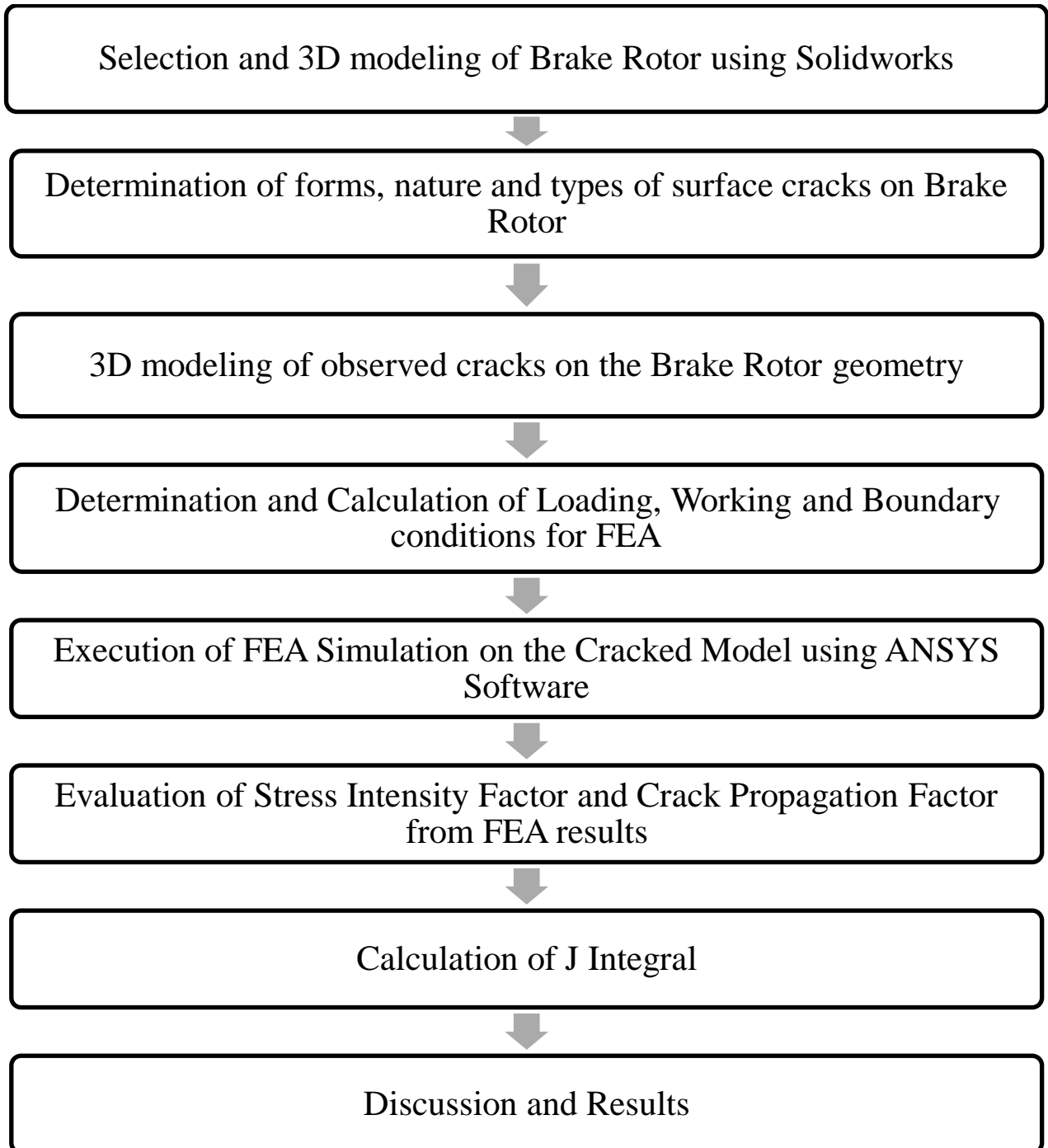


Fig 4.1: Methodology of the Project.

4.1 Methodology

Disk brakes are an essential component of automotive braking system but due to sudden stopping temperature is reached up to 900 degrees hence thermal stresses are induced in the disc material. This thermal stress produces a crack which leads to future serious failures. To overcome these failures, crack analysis is carried out. First of all from reference papers, a dimension is selected for sketching disc brake. 3D modeling software Solidworks is used for producing a CAD model. After this CAD file is saved as .IGES or .STEP file so ANSYS can read it as shell geometry. Structural analysis is carried out by using ANSYS Workbench 15.0.

By Structural analysis, there are where stresses are maximum. These are the spots where cracks will start to initiate. After finding these spots using ANSYS software a semi elliptical crack is generated and again transient structural is carried out to find J Integral and K factor of the model. These factors influence the crack growth rate and crack propagation rate of the model.

Chapter 5

Vehicle Specification and Theoretical calculation

5.1 Specification of Bajaj Pulsar 160cc Two Wheeler Bike

- Bike Bajaj Pulsar 160cc
- Engine Type Air Cooled, 4 Stroke, SI Engine
- Front brake Disc
- Displacement 149.2cc
- Maximum Power 12.73 bhp @ 8000 rpm
- Maximum Torque 12.80 Nm @ 5500 rpm
- Bore 57.3 mm
- Stroke 57.8 m



5.2 Theoretical Calculation of Disc Brake

Bajaj Pulsar 160 cc Disc brake Model

- Kerb weight -145 Kg.
- $U = 10$ m/s [Initial velocity]
- $V = 0$ m/s [Final velocity]
- Axle weight distribution factor,

$\gamma = 0.3$ [30%]

- Kinetic energy absorption factor,

$k = 0.75$ [75%]

Kinetic energy absorbed by brake = Kinetic energy during brake

$$\Delta K.E = k (\Delta K.E)$$

$$\Delta K.E = 0.75 [1/2(\gamma.m) (100)]$$

$$\Delta K.E = 0.75 [1/2(0.3m) (100)]$$

$$\Delta K.E = 1620 \text{ Nm}$$

$$\Delta K.E = 1620 \text{ J}$$

Therefore power required to half = $\Delta K.E /tb = 1620/6 = 270W$

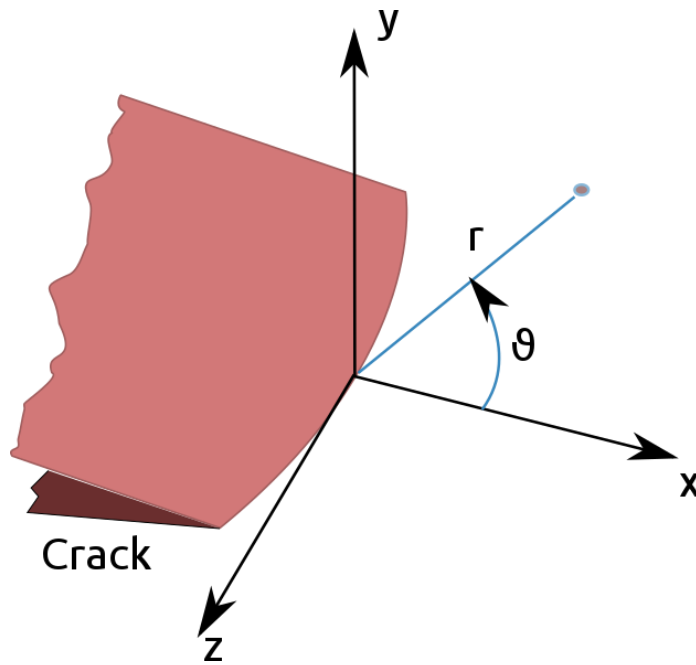
Chapter 6

J-Integral & Stress Intensity Factor

6.1. Stress Intensity Factor

6.1.1 Introduction

The stress intensity factor is used in fracture mechanics to predict the stress state ("stress intensity") near the tip of a crack caused by a remote load or residual stresses. It is a theoretical construct usually applied to a homogeneous, linear elastic material and is useful for providing a failure criterion for brittle materials, and is a critical technique in the discipline of damage tolerance. The concept can also be applied to materials that exhibit small-scale yielding at a crack tip.



The magnitude of K depends on sample geometry, the size and location of the crack, and the magnitude and the modal distribution of loads on the material.

Linear elastic theory predicts that the stress distribution (σ) near the crack tip, in polar coordinates (r, θ) with origin at the crack tip, has the form.

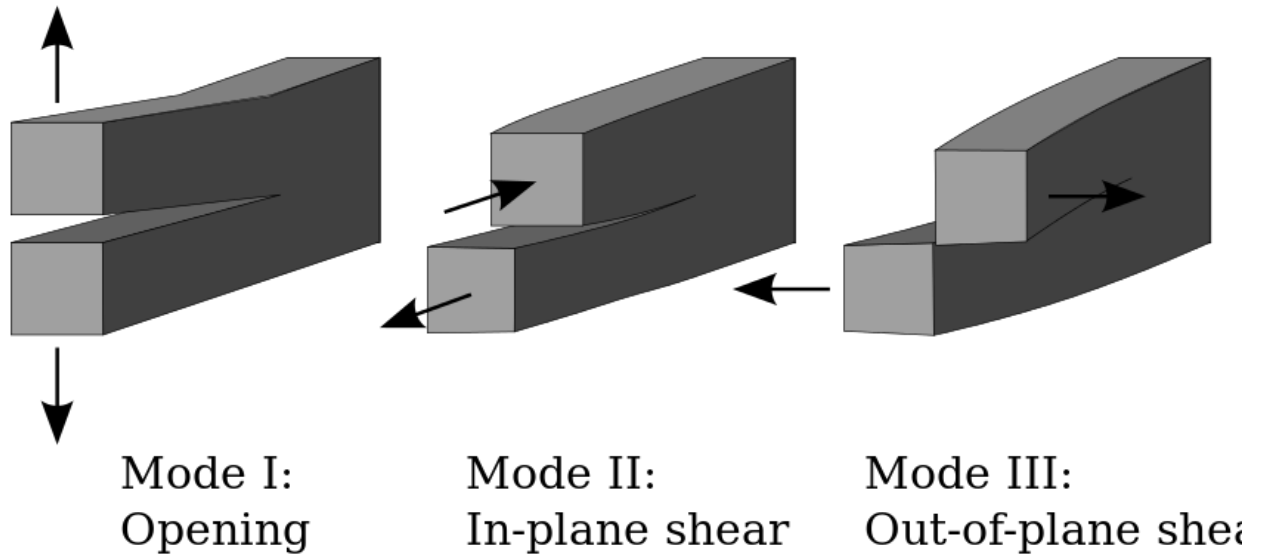
$$\sigma(r, \theta) = \frac{K}{\sqrt{2\pi r}} f(\theta)$$

Where, $K = \sigma\sqrt{\pi a}$

Where K is the stress intensity factor (with units of stress length^{1/2}) and f is a dimensionless quantity that varies with the load and geometry and 'a' is the half of crack width. This relation breaks down very close to the tip (small r) because as r goes to 0, the stress σ goes to infinity resulting in a stress singularity, which can be avoided by representing a crack as a round tipped notch. Plastic distortion typically occurs at stresses exceeding the material's yield strength and the linear elastic solution is no longer applicable close to the crack tip. However, if the crack-tip plastic zone is small, it can be assumed that the stress distribution near the crack is still given by the above relation.

6.1.2 Modes of Crack Failures

Three linearly independent cracking modes are used in fracture mechanics. These load types are categorized as Mode I, II, or III



Mode I, shown to the left, is an opening (tensile) mode where the crack surfaces move directly apart. Mode II is a sliding (in-plane shear) mode where the crack surfaces slide over one another in a direction perpendicular to the leading edge of the crack. Mode III is a tearing (anti-plane shear) mode where the crack surfaces move relative to one another and parallel to the leading edge of the crack. Mode I is the most common load type encountered in engineering design.

Different subscripts are used to designate the stress intensity factor for the three different modes. The stress intensity factor for mode I is designated K_I and applied to the crack opening mode. The mode II stress intensity factor, K_{II} , applies to the crack sliding mode and the mode III stress intensity factor, K_{III} , applies to the tearing mode.

6.2 Evaluation of J-Integral

The J-integral represents a way to calculate the strain energy release rate, or work (energy) per unit fracture surface area, in a material.^[1] The theoretical concept of J-integral was developed in 1967 by Cherepanov and in 1968 by Jim Rice independently, who showed that an energetic contour path integral (called J) was independent of the path around a crack. The J-integral is equal to the strain energy release rate for a crack in a body subjected to monotonic loading.^[6] This is generally true, under quasistatic conditions, only for linear elastic materials. For materials that experience small-scale yielding at the crack tip, J can be used to compute the energy release rate under special circumstances such as monotonic loading in mode III (anti-plane

shear). The strain energy release rate can also be computed from J for pure power-law hardening plastic materials that undergo small-scale yielding at the crack tip.

6.3 Relation between J-Integral & K factor:

The J integral and the stress intensity factor (SIF) K are both important research objects of fracture mechanics, and are often employed to establish criteria for crack propagation. The relationship between them has always been a research hotspot. In this paper, the SIF can be obtained conveniently by the scaled boundary finite element method (SBFEM) due to the fact that analytical solution can be obtained along the radial direction for stress singularity problems. The J integral can be solved analytically using the formulae between J and K for mixed mode crack with arbitrary inclination in elastic materials. Factors that affect the accuracy of SIF and J integral, such as the distance between the crack and outer boundary, size of the discretized elements and partition of the domain into super-elements. The relation between J-Integral and SIF Factor K for plane stress is given by

$$J = \frac{K^2}{E}$$

Where 'E' is Young's Modulus.

Chapter 7

3D Modelling using Solidworks

7.1 Modeling of Disc plate using Solidworks

7.1.1 Introduction to SOLIDWORKS

Solid works is a solid-modeling computer aided design (CAD) and computer aided engineering (CAE) computer program that runs on Microsoft windows. Solid works is published by Dassault systems. Solid works currently markets several versions of the Solid works CAD software in addition to e-drawings, a collaboration tool and a draft sight a 2D CAD product. Building a model in Solid works usually starts with a 2D sketch. The sketch generally consists of geometry such as points, arcs, conics (except hyperbolas) and splines. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside the sketch.

Solidworks also includes additional advanced modeling features such as gear mating and cam follower mates which allow model gear assemblies to accurately reproduce the rotational movement of the actual gear train.

7.2.1 Detail Drawing of Disc Brake:

Below figure shows detailed drawing of Disc brake made using Solidworks software.

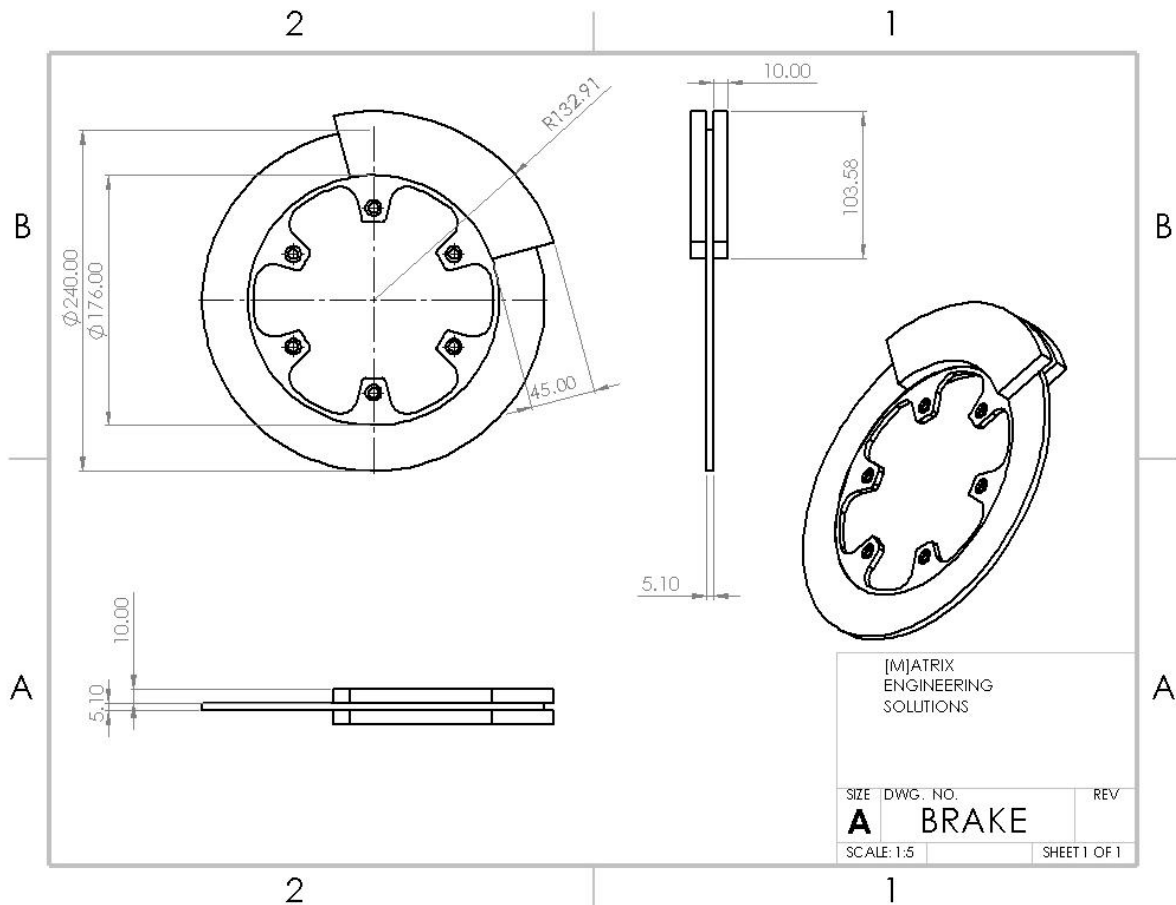


Fig. 7.2.1 Detailed drawing of Disc Brake model.

7.2.2 Procedure for 3D modeling using Solidworks

Step 1: Double click on the Solidworks icon, Solidworks will open and select Part. Now Solidworks working window will open then first select the dimension standards in millimeters.

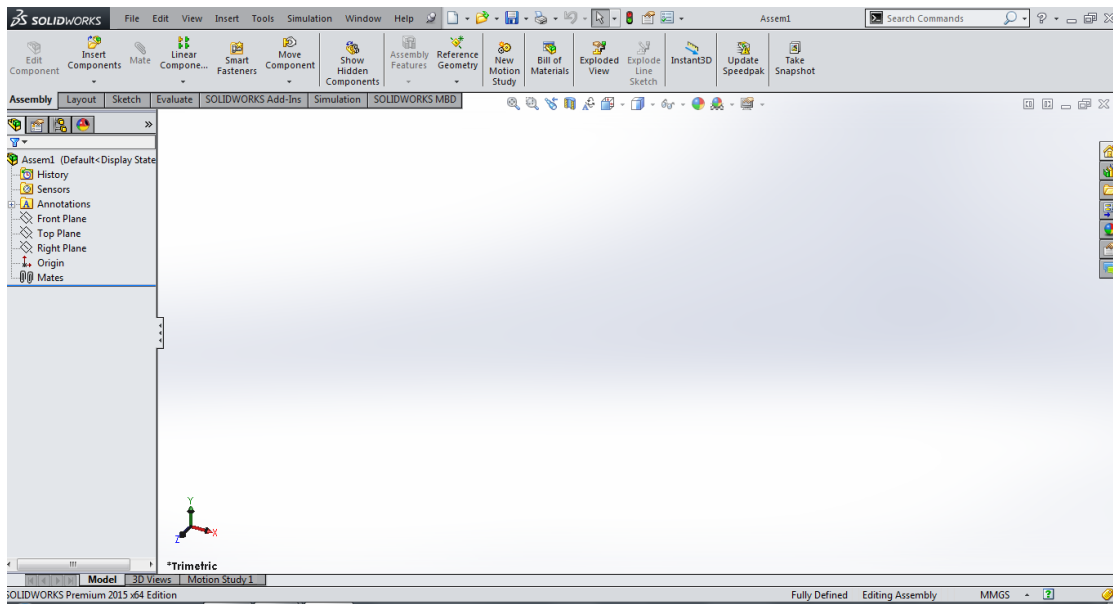


Fig 7.2.2: Working Window of Solidworks 2015.

Step 2: Select plane and sketch on that according to the dimension as shown in Fig

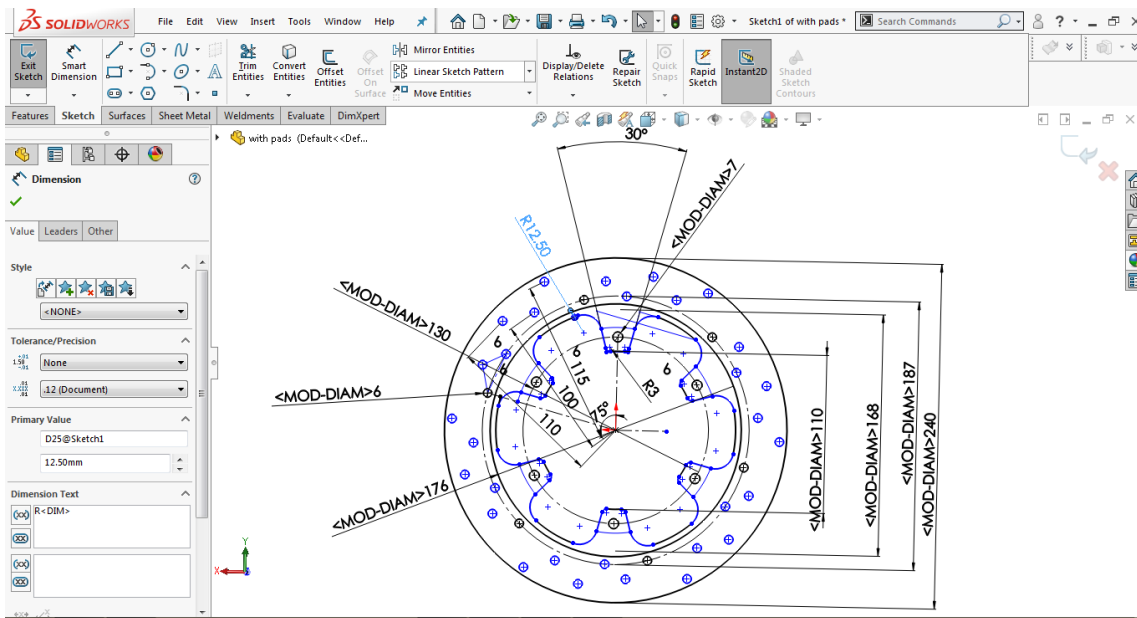


Fig 7.2.3: Sketch feature is used.

Step 3: Select plane and sketch on the inner ring and extrude by using the extrude command as shown in fig.

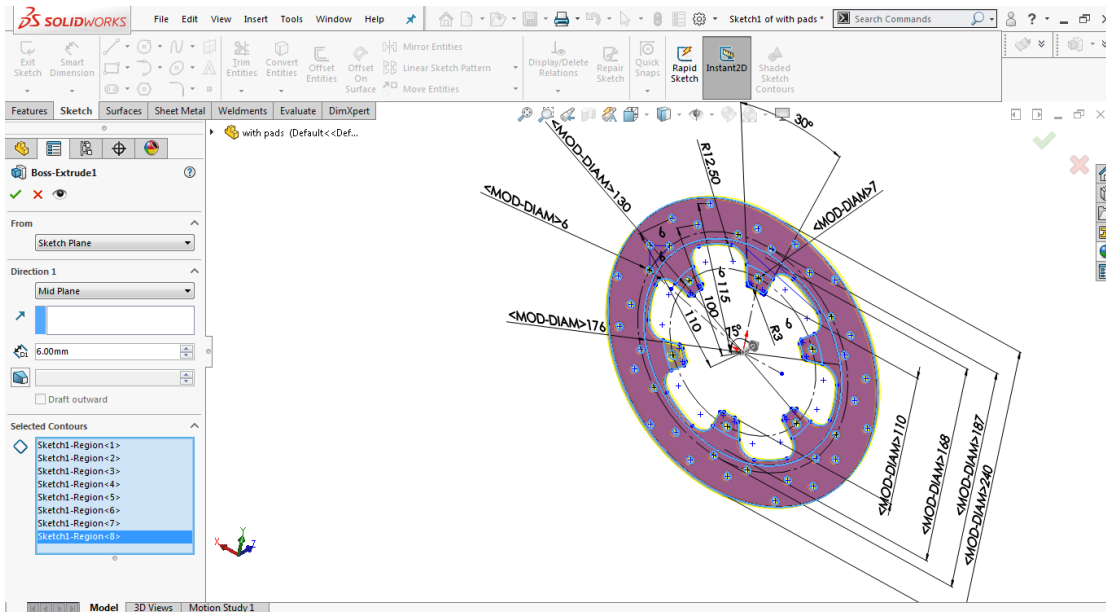


Fig 7.2.4: Extrude feature is used.

Step 4: Sketch Pads along the surface for given dimensions.

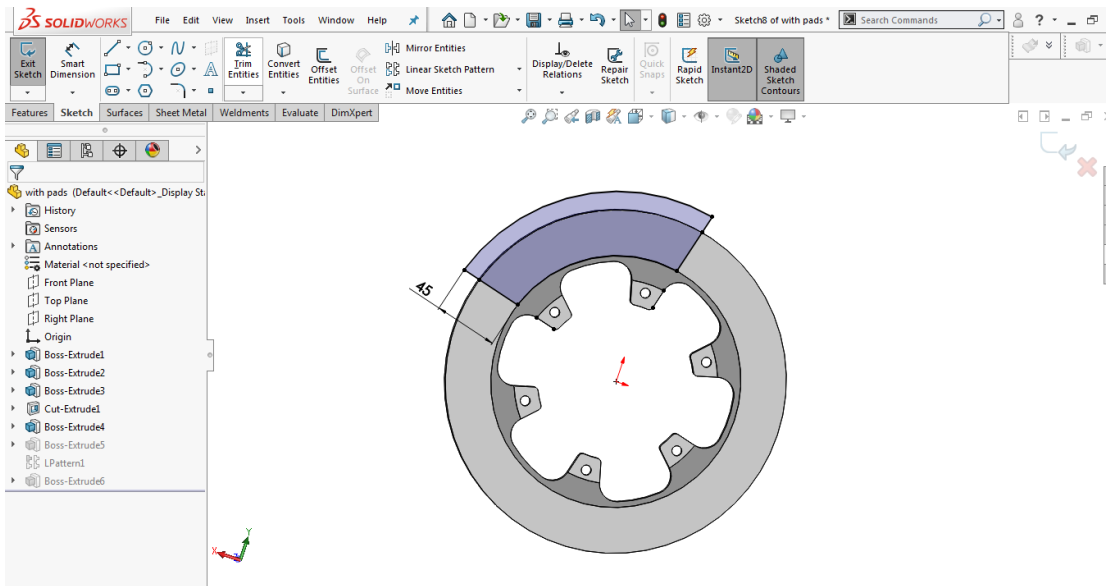


Fig 7.2.5 Sketch Feature Is Used For Brake Pads

Step 5: Extrude the sketched part.

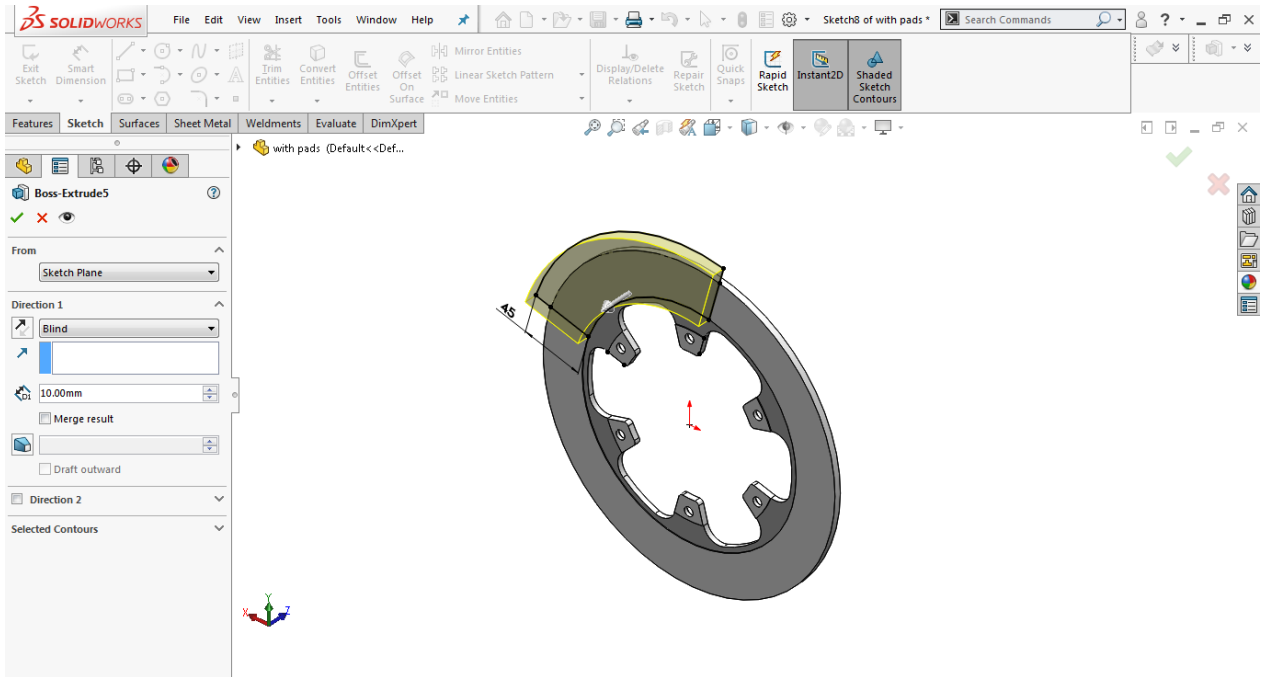


Fig 7.2.6: Extrude feature is used for making brake pads

Step 6: 3D CAD model of Solidworks.

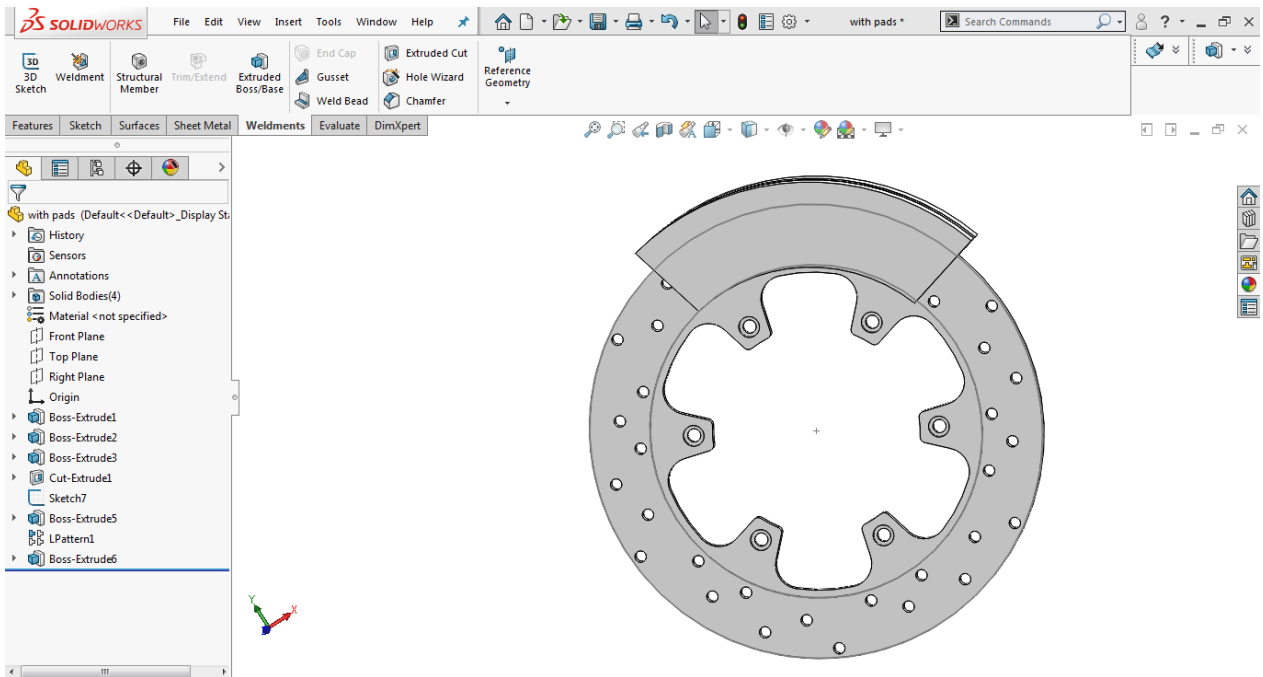


Fig 7.2.7: CAD Model of Disc Brake with Pads

Step 6: Rendered part of Original Disc brake model

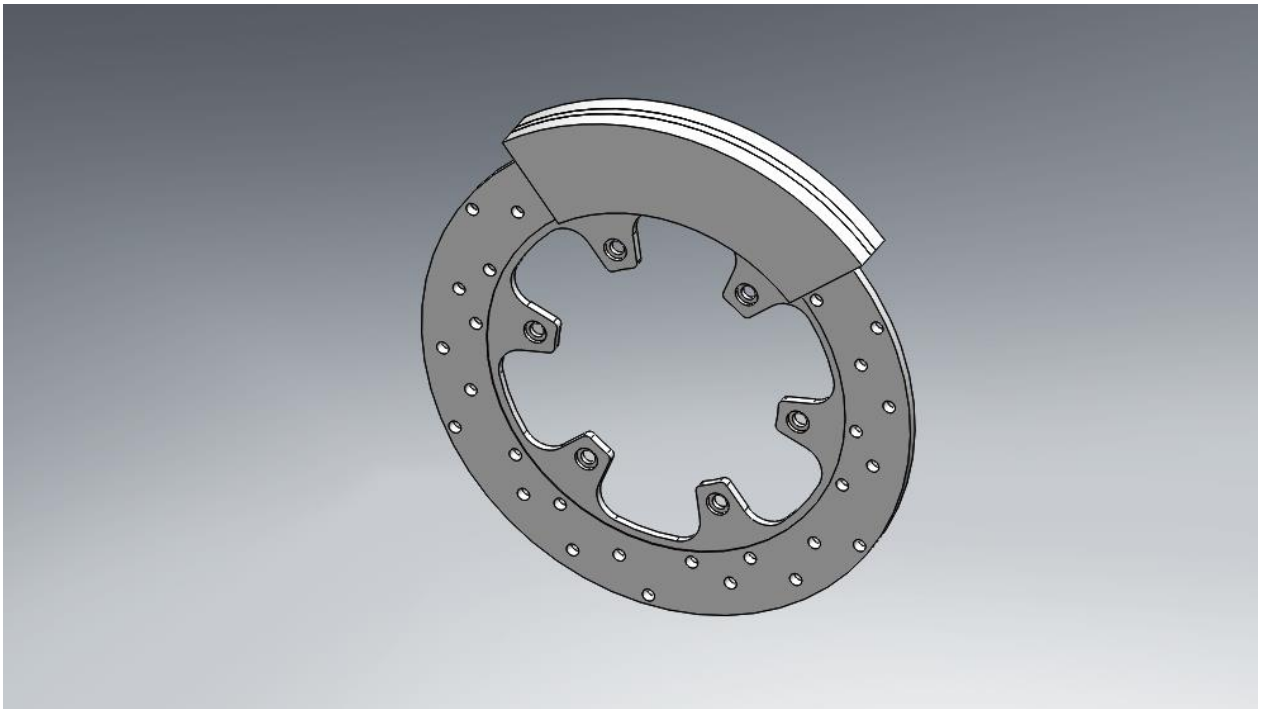


Fig 7.2.8: Rendered Part of Original Disc brake

Chapter 8

Simulation of Disc brake using FEA

8.1 Introduction to FEA

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

FEA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual object.

Finite element analysis helps predict the behavior of products affected by many physical effects, including:

- Mechanical stress
- Mechanical vibration
- Fatigue
- Motion
- Heat transfer
- Fluid flow
- Electrostatics
- Plastic injection moldings

8.2 Procedure in FEA

Finite Element Analysis is a mathematical representation of a physical system comprising a part/assembly (model), material properties, and applicable boundary conditions {collectively referred to as pre-processing}, the solution of that mathematical representation {solving}, and the study of results of that solution {post-processing}.

8.2.1 Pre-Processing

- Define the geometric domain of the problem.
- Define the element type(s) to be used.
- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area, and the like).
- Define the element connectivity (mesh the model).
- Define the physical constraints (boundary conditions).
- Define the loadings.

8.2.2 Solution

- Computes the unknown values of the primary field variable(s)
- Computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow.

8.2.3 Post Processing

- Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution.
- It deals with the representation of result. Typically, the deformed configuration, modes shapes, temperature, and stress distribution are computed and displayed at this stage.

For this case, coupled analysis is used. Firstly steady State-thermal is performed and then Transient structural is performed to obtain crack analysis.

8.3 Steps for Steady-State Thermal and Transient Structural Analysis.

Step 1: Double click on ANSYS Workbench 18.0 icon, working window of FEA software will open.

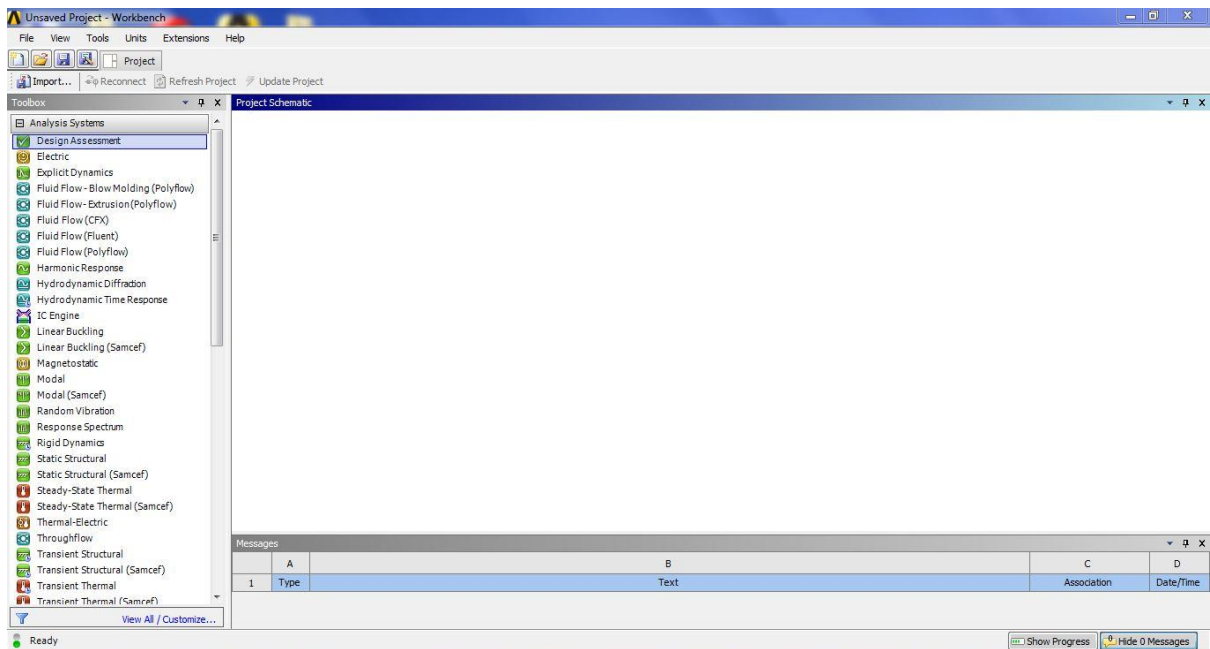


Fig.8.3.1: Homepage of ANSYS Workbench 18.0.

Step 2: Click on units located on tool bar and select unit format as per requirement. Double click on Steady-State Thermal from Analysis system which is present on left side of window.

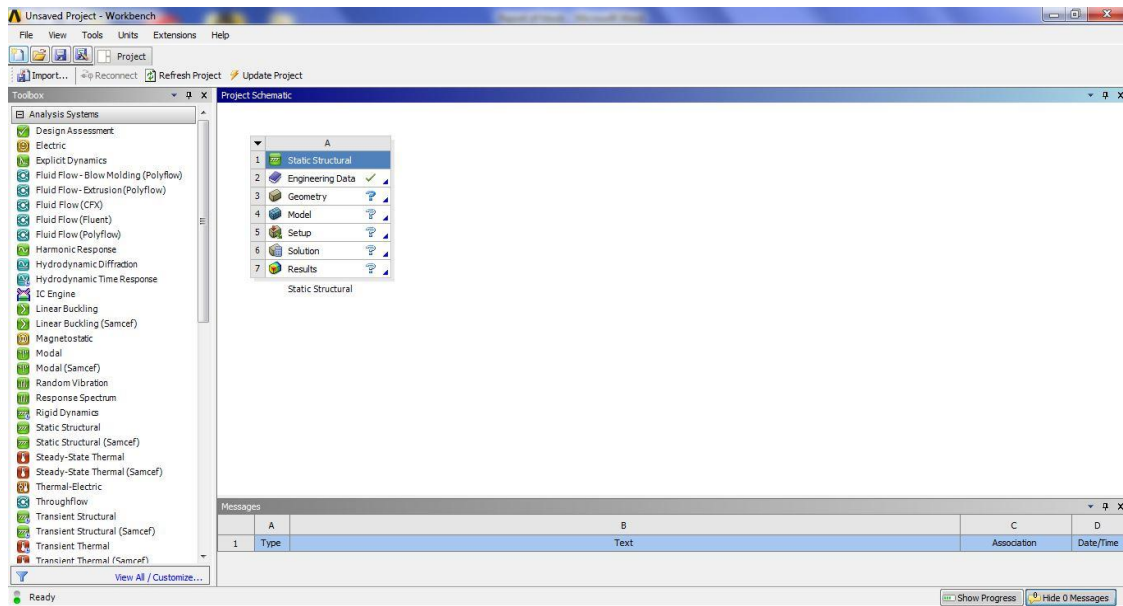


Fig.8.3.2: Selection of Static Structural from Analysis System

Step 3: Double click on Engineering Data for selection of material. Click on Engineering Data Sources. To assign material to component which is not present in general materials for that add material to library by giving their properties. Write name of material at bottom of Engineering Data Sources. Give location to material then add desirable properties by click on properties from left window

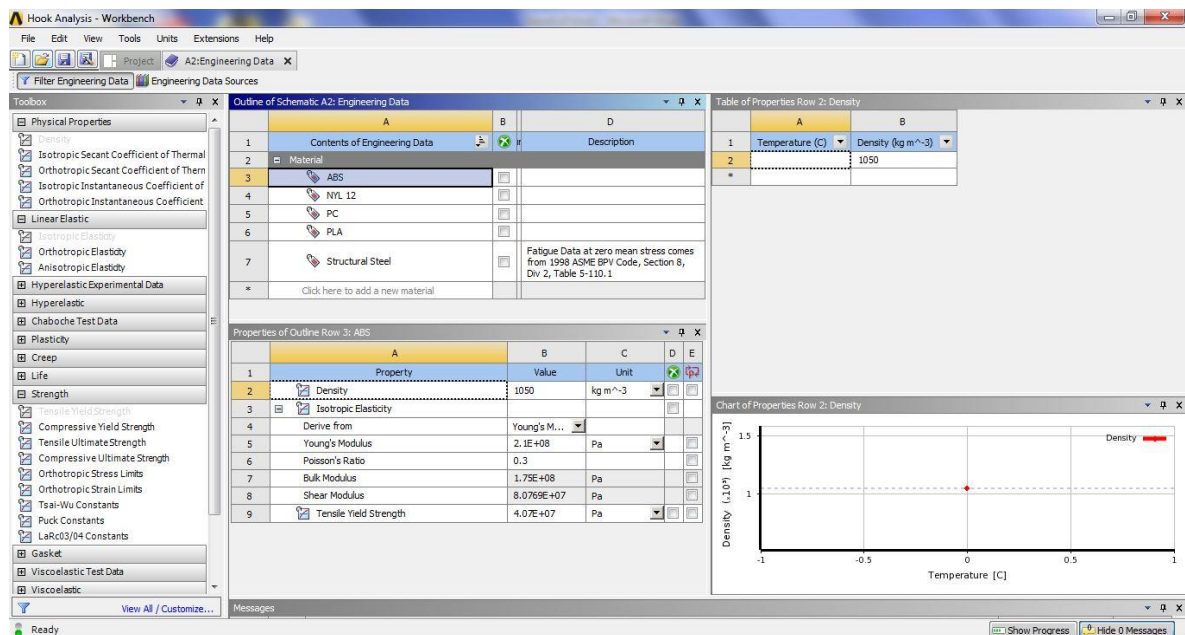


Fig 8.3.3: Defining Materials in Engineering Data Sources.

8.4 Simulation Results of Disc brake

8.4.1 Meshing of the geometry.

- Medium Size adaptive global mesh applied on the entire geometry
- Automatic Meshing is used.
- Tetrahedron mesh type is selected for disc and circular type mesh is selected for pads.

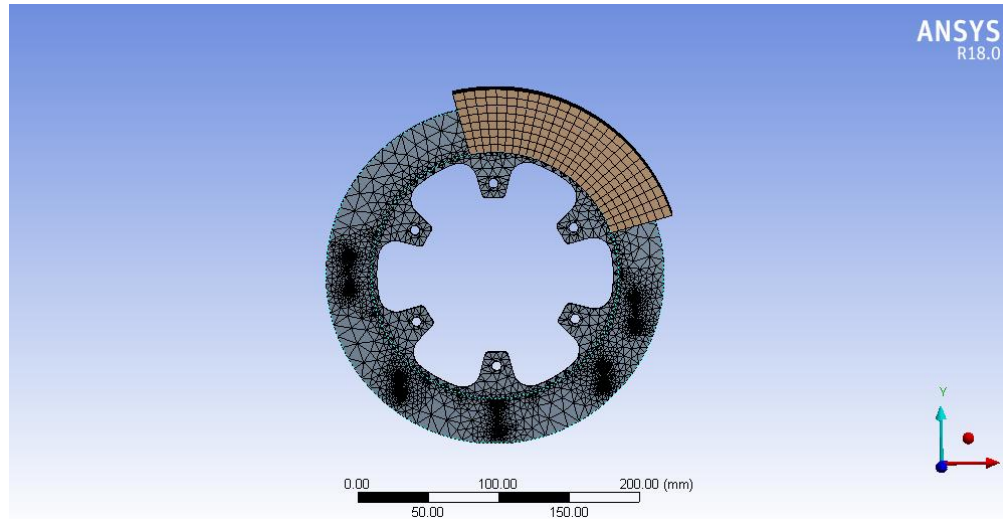


Fig 8.4.1 Mesh for Steady State Thermal

8.4.2 Fracture

There are two ways in which crack can be analysed.

- Firstly using Premeshed Technique where crack is already generated in CAD modelling software and after that setting meshing for cracks and J-Integral and K factor can be found out for the given crack surface.
- Secondly, Crack can be built in ANSYS Workbench by assigning coordinates, setting the type of crack i.e. Semi-elliptical and going for mesh and J-Integral and stress Intensity Factor Analysis.

For this analysis five semi-elliptical cracks are generated at different places. The fracture is shown for the given model.

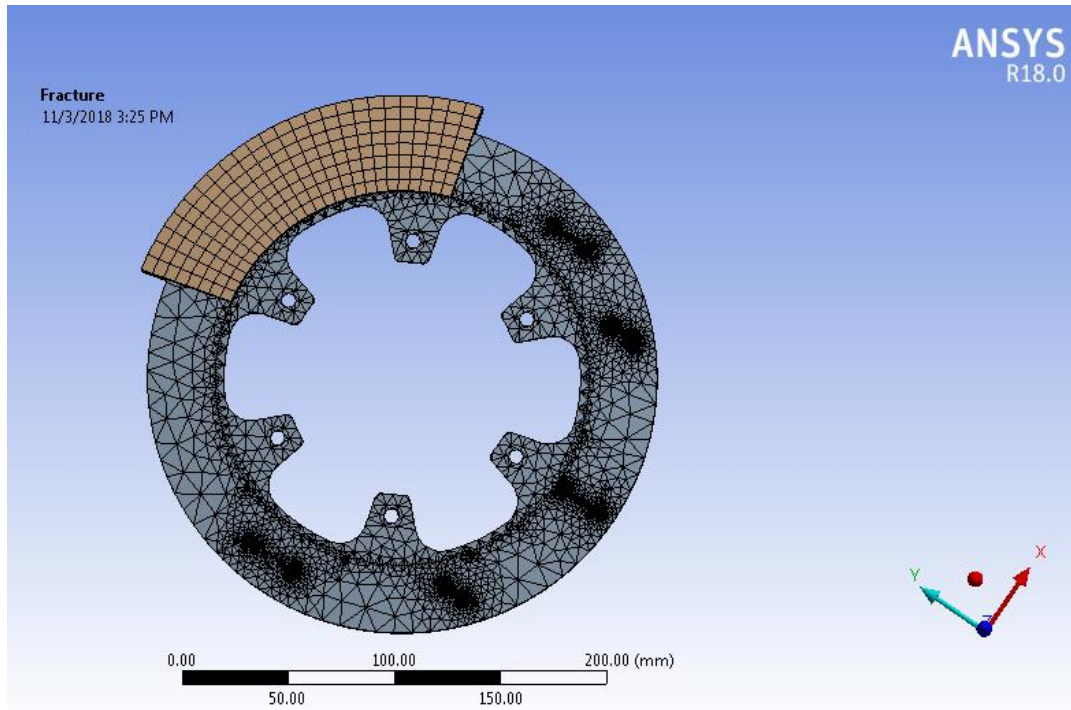


Fig 8.4.2 Fracture mesh for the Disc Brake rotor

8.4.3 Boundary Conditions for Steady State Thermal

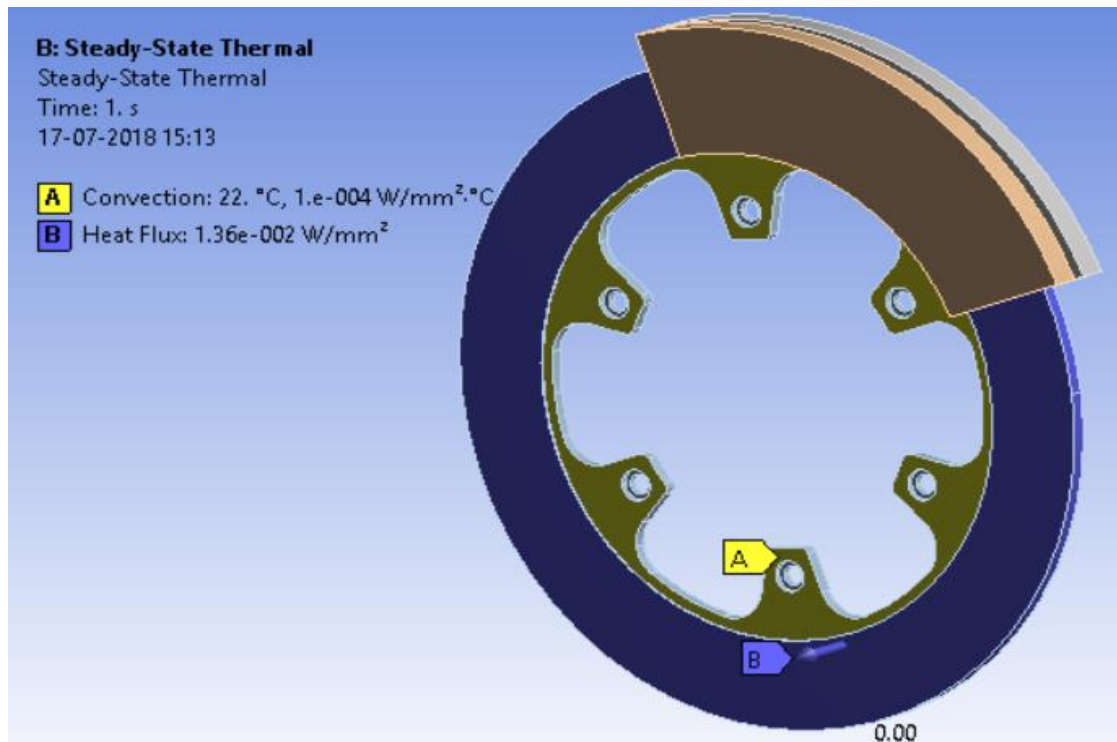


Fig 8.4.3 Boundary Conditions for Steady State Thermal

8.4.4 Boundary Conditions for Transient Structural

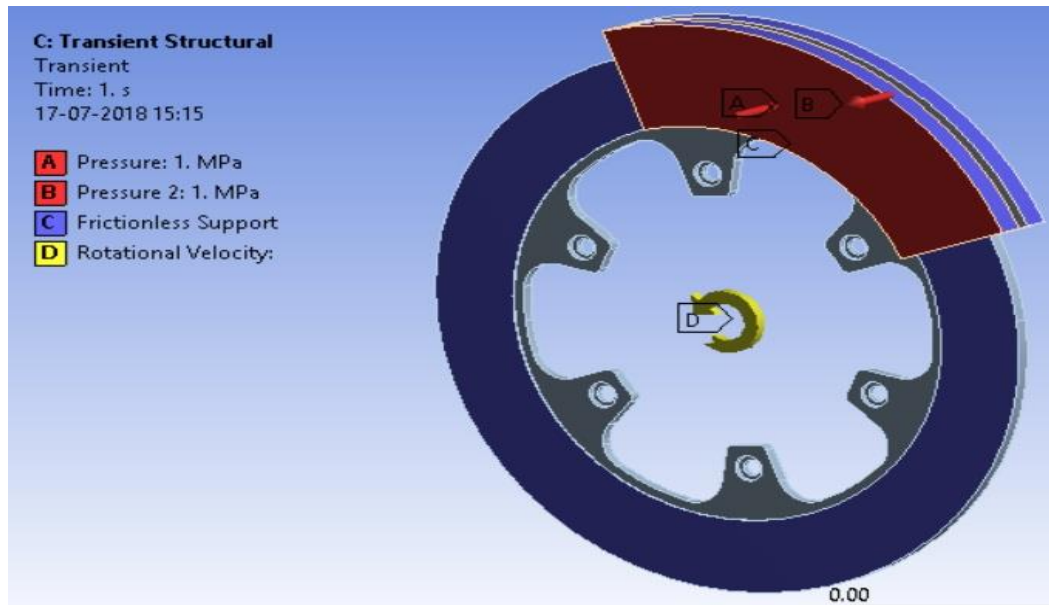


Fig 8.4.4 Boundary Condition for Static Structural

8.5. Simulation Results for Steady-State Thermal Analysis

8.5.1 Surface Temperature

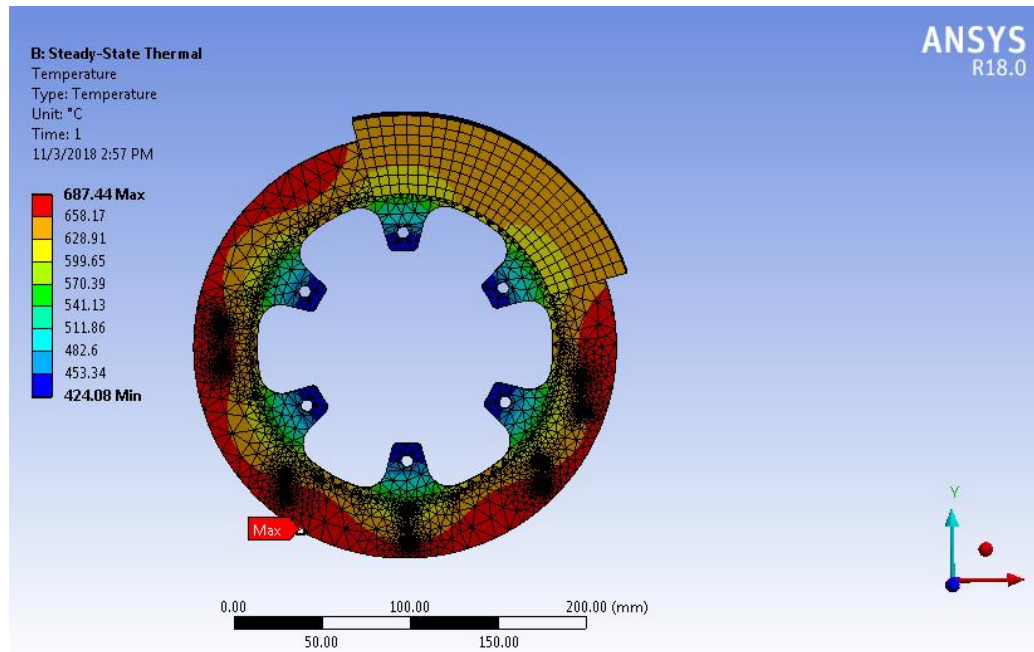


Fig 8.5.1 Surface Temperature for Disc Brake.

8.5.2 Total Heat Flux

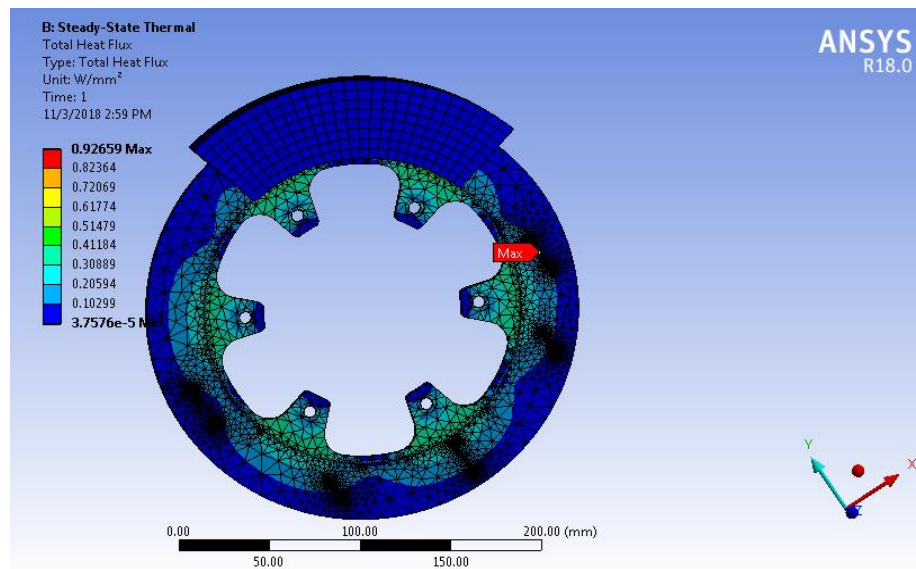


Fig 8.5.2 Total Heat flux

8.6 Simulation Results for Transient Structural Analysis

For coupled analysis the simulated results and geometry is imported from results in steady state thermal analysis.

8.6.1 Equivalent Stresses for disc rotor

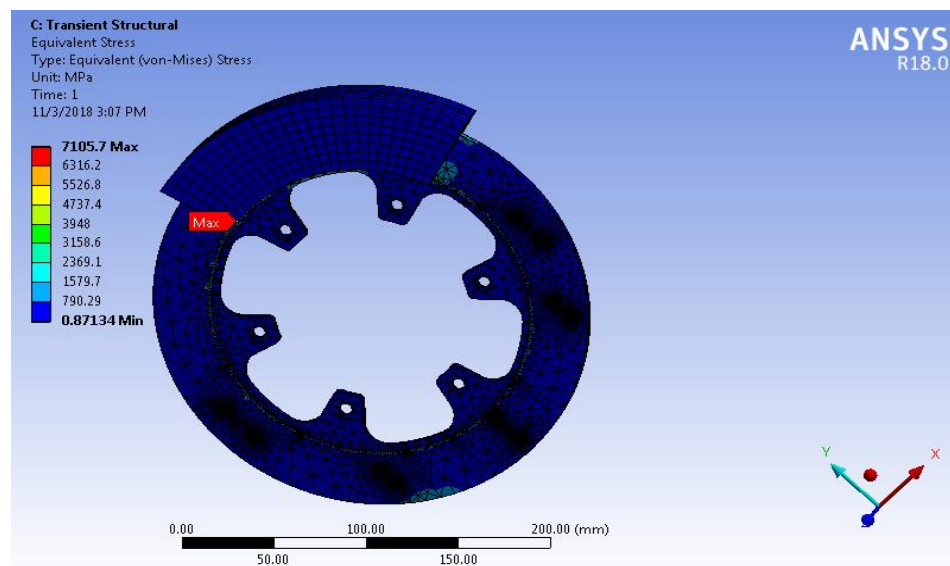


Fig 8.5.1 Von mises Stresses for Transient structural

8.6.2 Total Deformation.

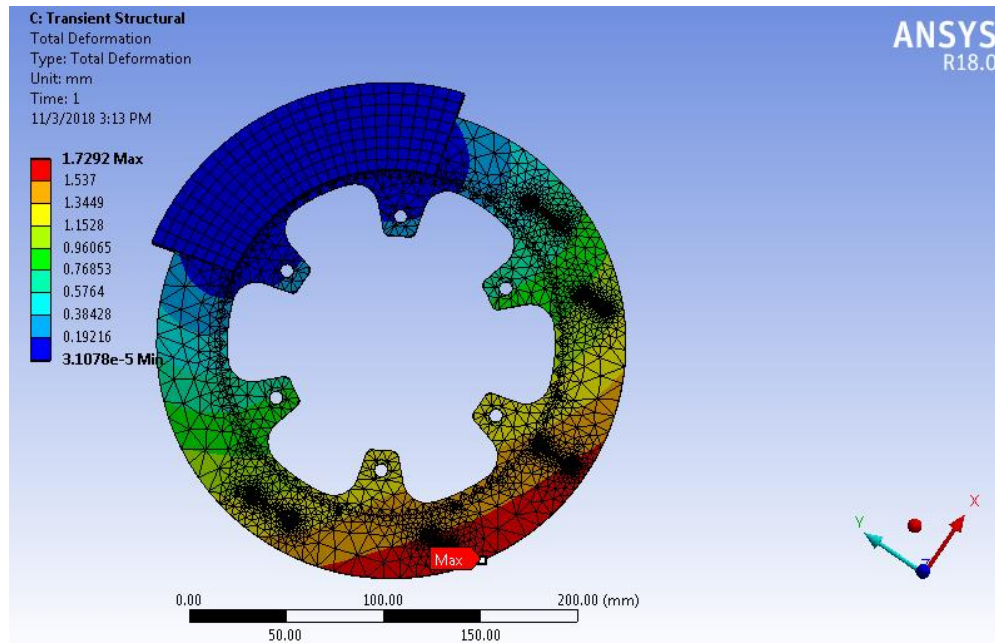


Fig 8.6.2 Total Deformation for Transient structural

8.6.3 Fatigue analysis for Life span of system.

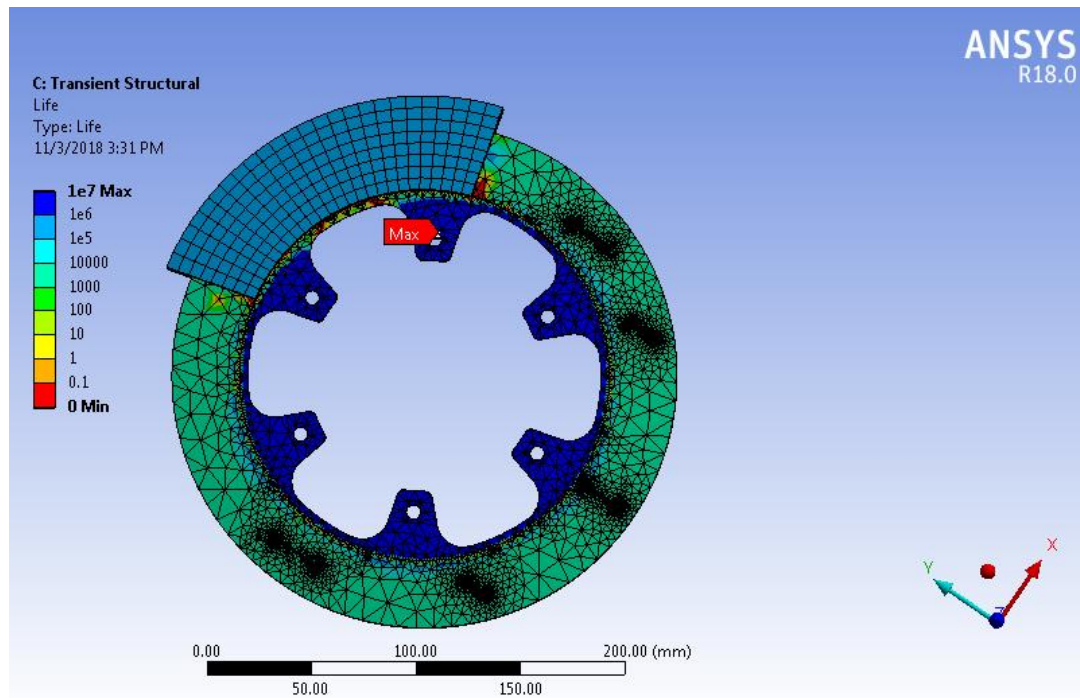


Fig 8.6.2 Total Life

8.7 Simulation Results for Crack Analysis

8.7.1 Crack 1:

For crack 1, major radius selected for the semi-elliptical crack is 10mm and minor radius selected is 1mm. The Analysis results for three modes of Stress Intensity factors i.e. K_1 , K_2 , K_3 and J-Integral evaluation is shown.

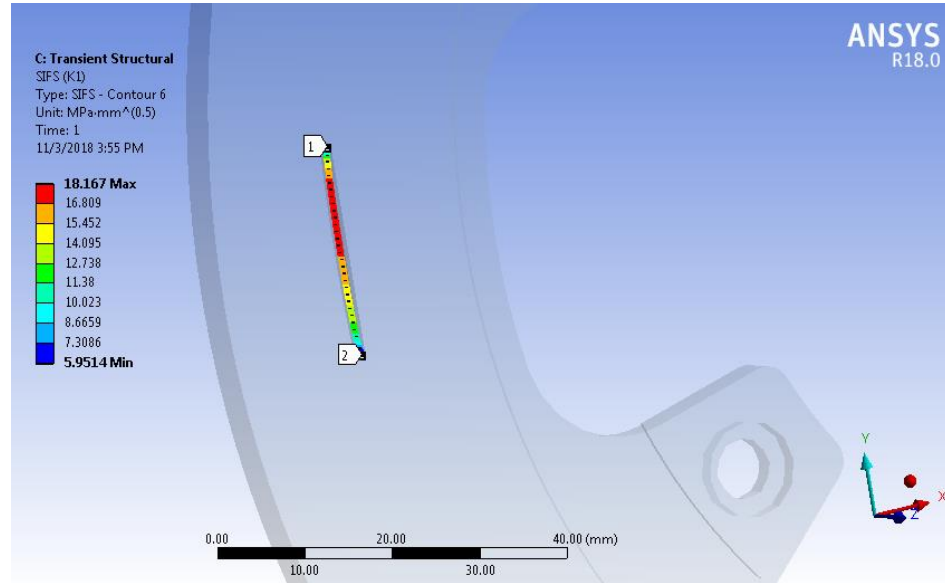


Fig. 8.7.1 Stress Intensity Factor K_1 analysis

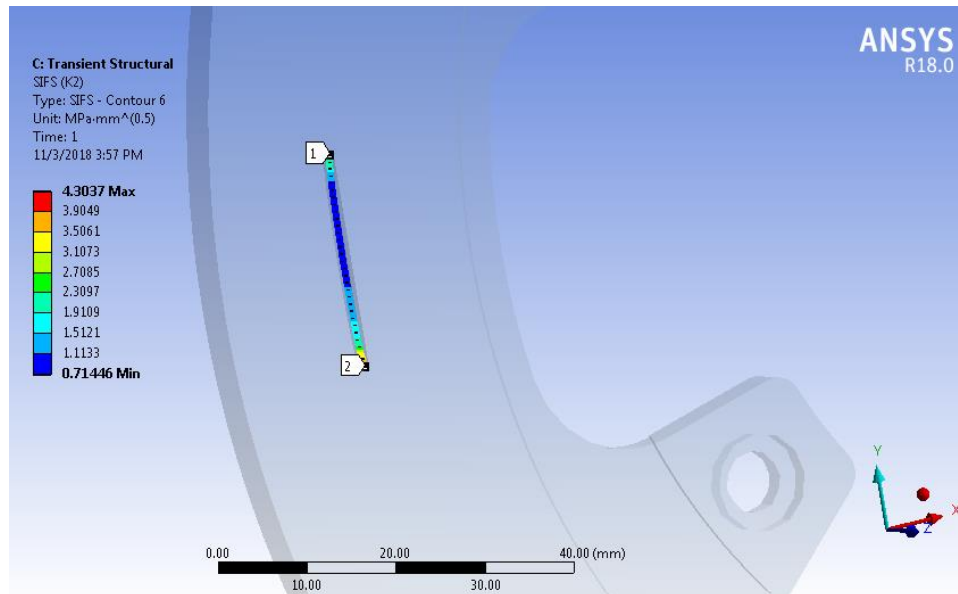


Fig 8.7.2 Stress Intensity Factor K_2 analysis

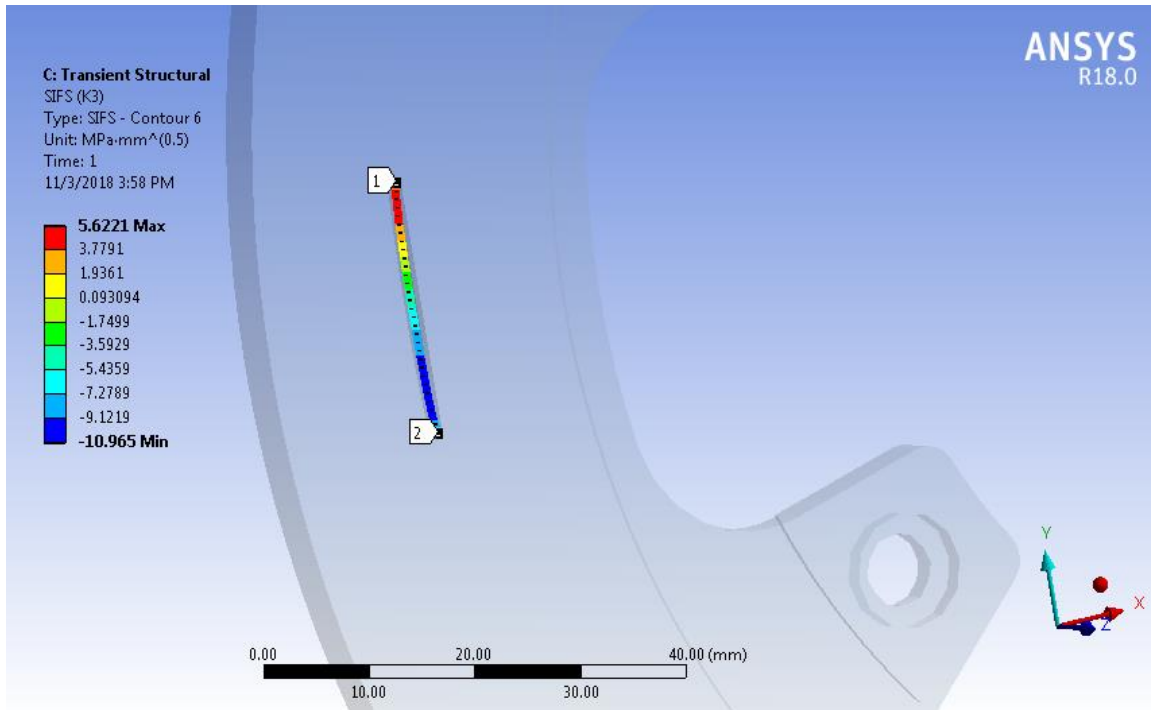


Fig 8.7.3 Stress Intensity Factor K3 analysis

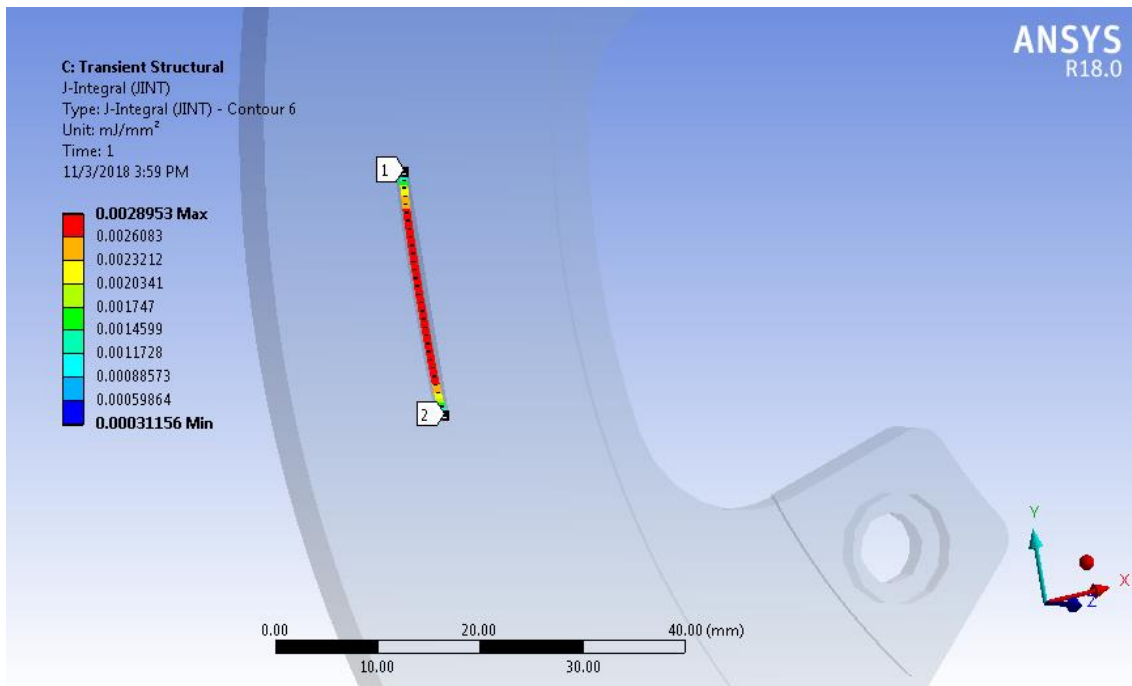


Fig 8.7.4 J-Integral Factor analysis

8.7.2 Crack 2:

For crack 1, major radius selected for the semi-elliptical crack is 10mm and minor radius selected is 2mm. The Analysis results for three modes of Stress Intensity factors i.e. K_1 , K_2 , K_3 and J-Integral evaluation is shown.

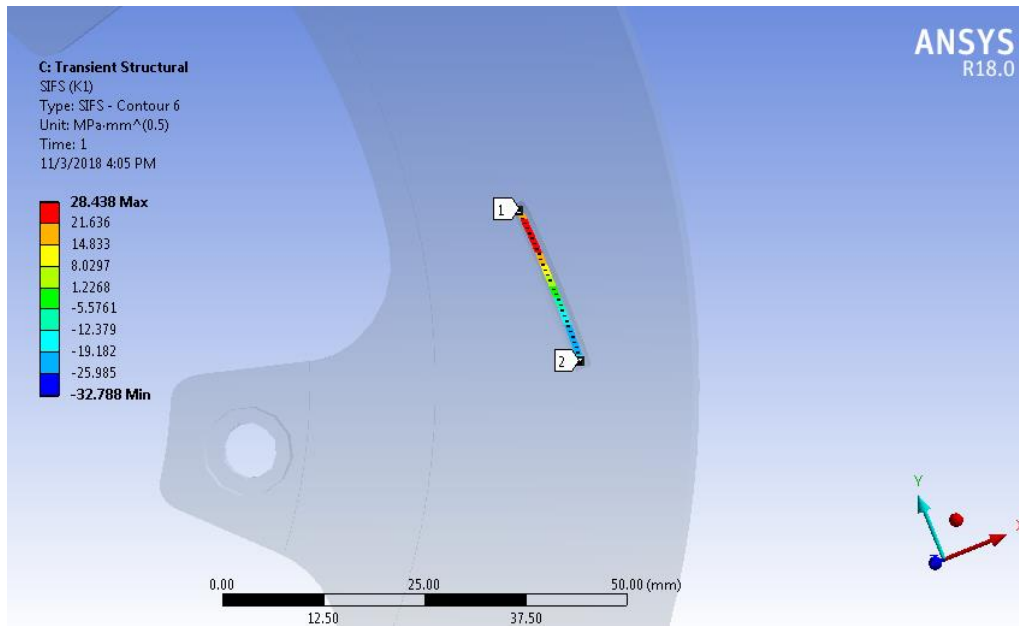


Fig 8.7.5 Stress Intensity Factor K1 analysis

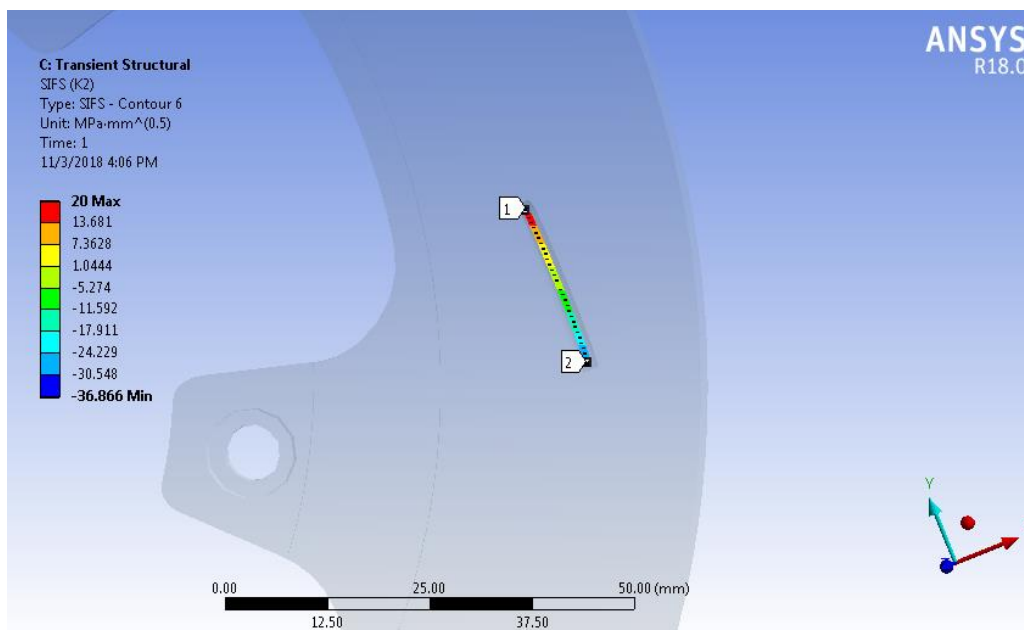


Fig 8.7.6 Stress Intensity Factor K2 analysis

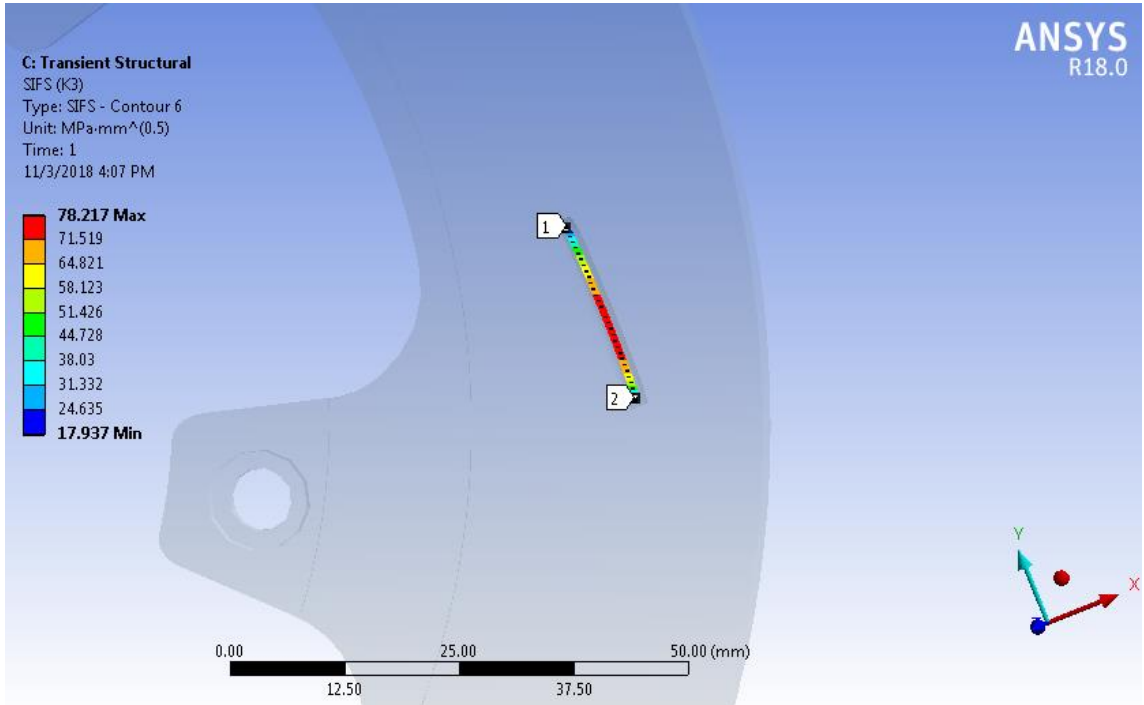


Fig 8.7.7 Stress Intensity Factor K3 analysis

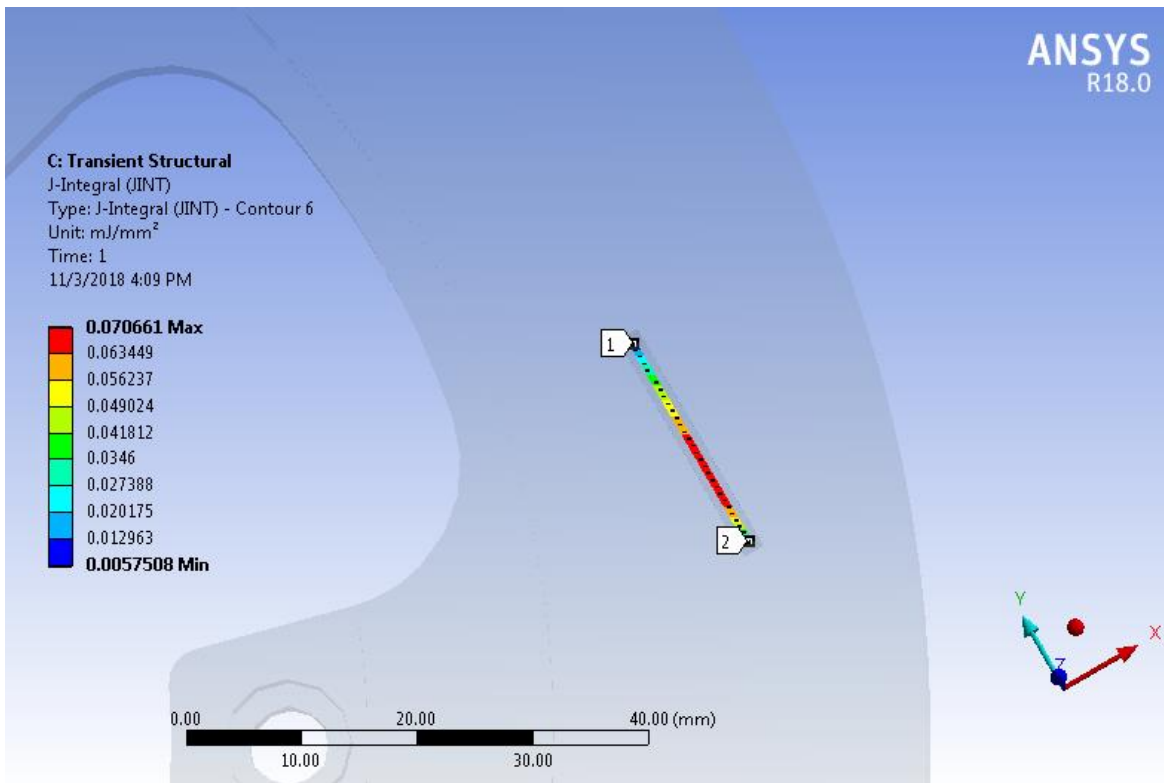


Fig 8.7.8 J-Integral Factor analysis

8.7.3 Crack 3:

For crack 3, major radius selected for the semi-elliptical crack is 10mm and minor radius selected is 2mm. The Analysis results for three modes of Stress Intensity factors i.e. K1, K2, K3 and J-Integral evaluation is shown.

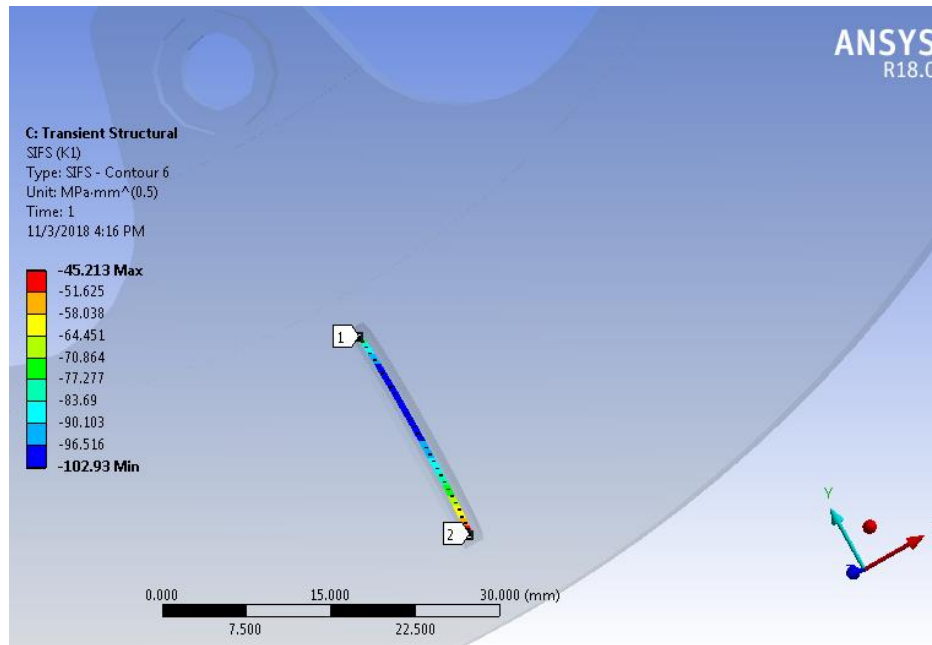


Fig 8.7.9 Stress Intensity Factor K1 analysis

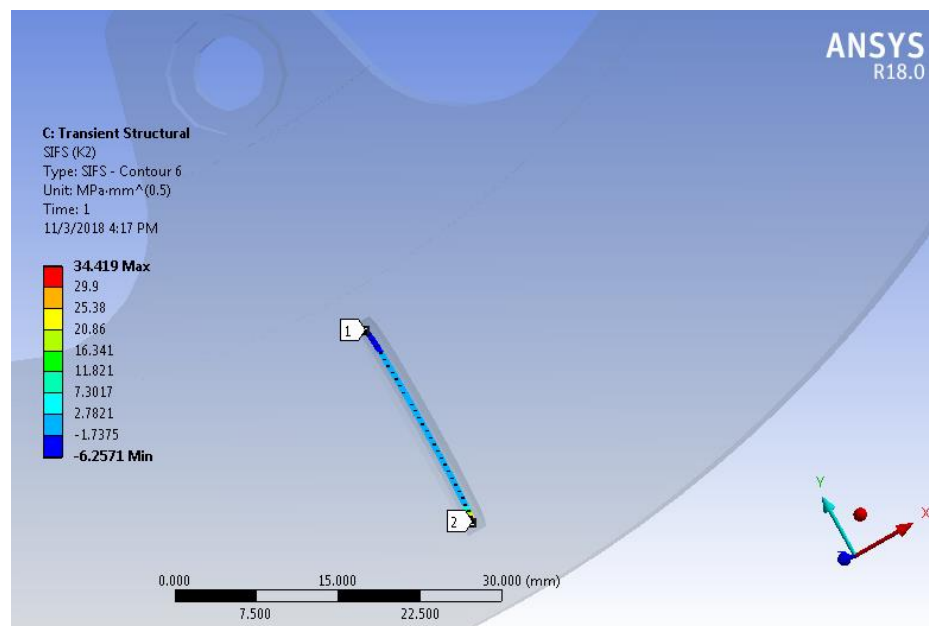


Fig 8.7.10 Stress Intensity Factor K2 analysis

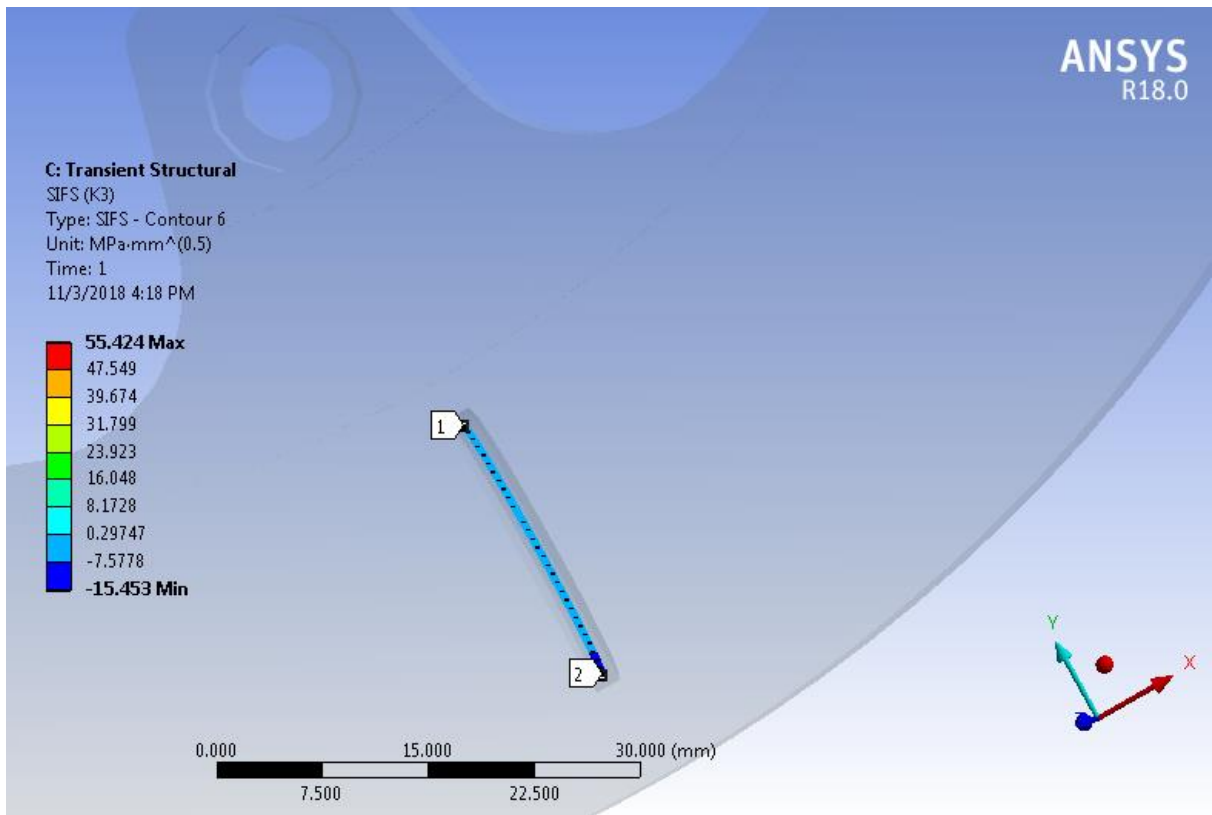


Fig 8.7.11 Stress Intensity Factor K3 analysis

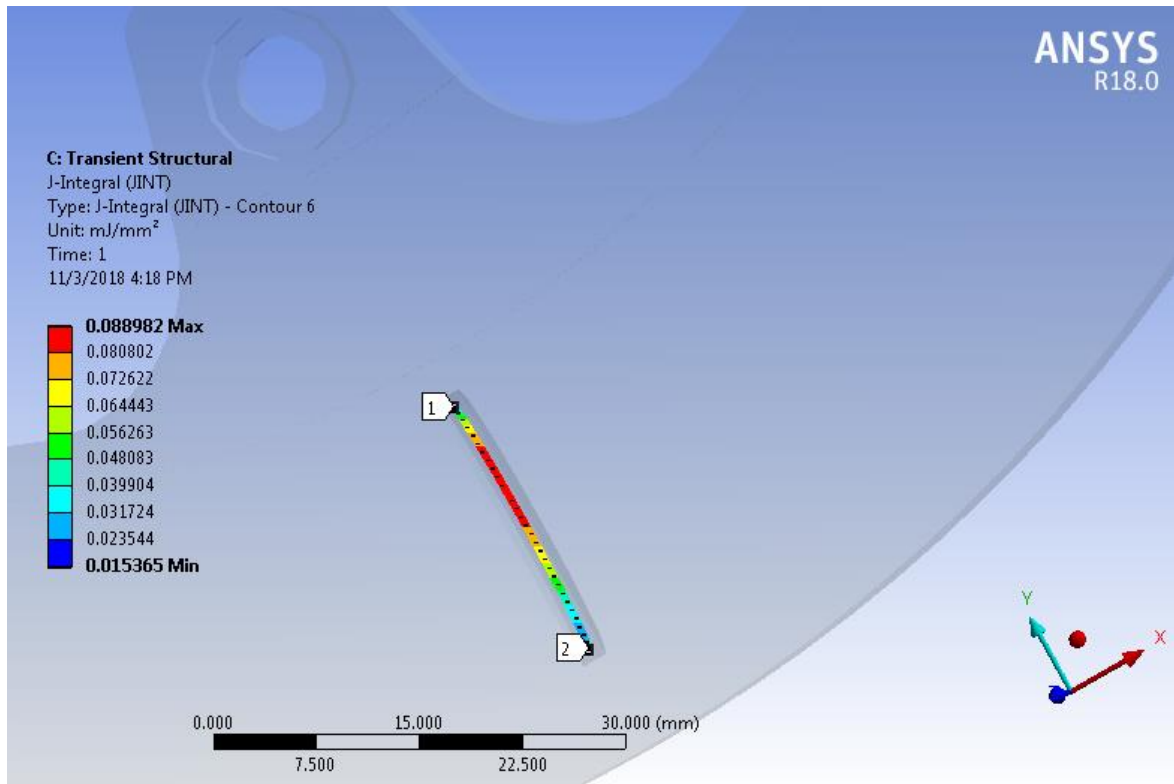


Fig 8.7.12 J-Integral Factor analysis

8.7.4 Crack 4:

For crack 4, major radius selected for the semi-elliptical crack is 6mm and minor radius selected is 1.5mm. The Analysis results for three modes of Stress Intensity factors i.e. K1, K2, K3 and J-Integral evaluation is shown.

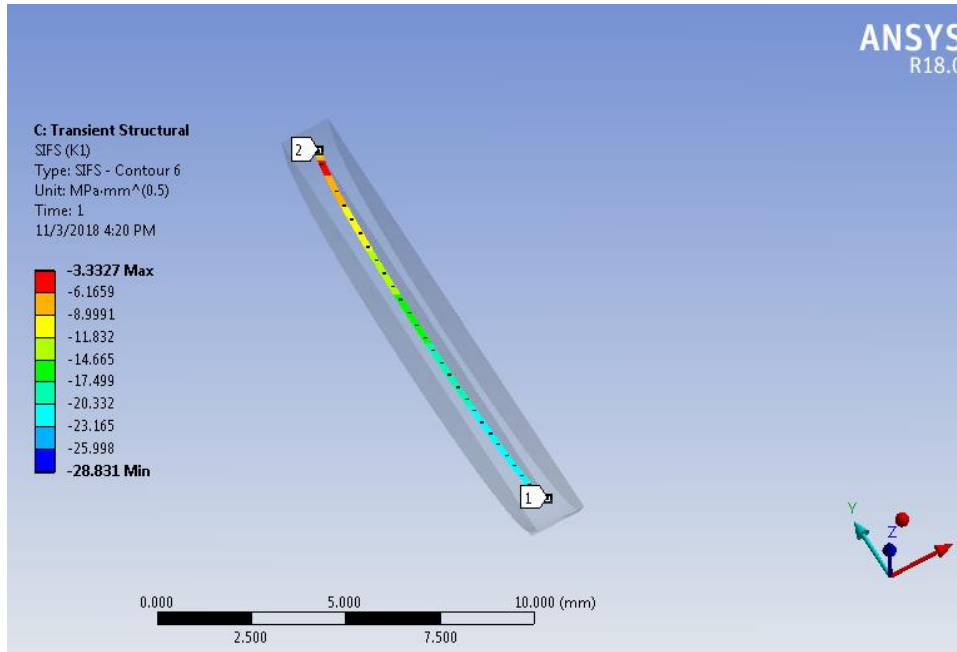


Fig 8.7.13 Stress Intensity Factor K1 analysis

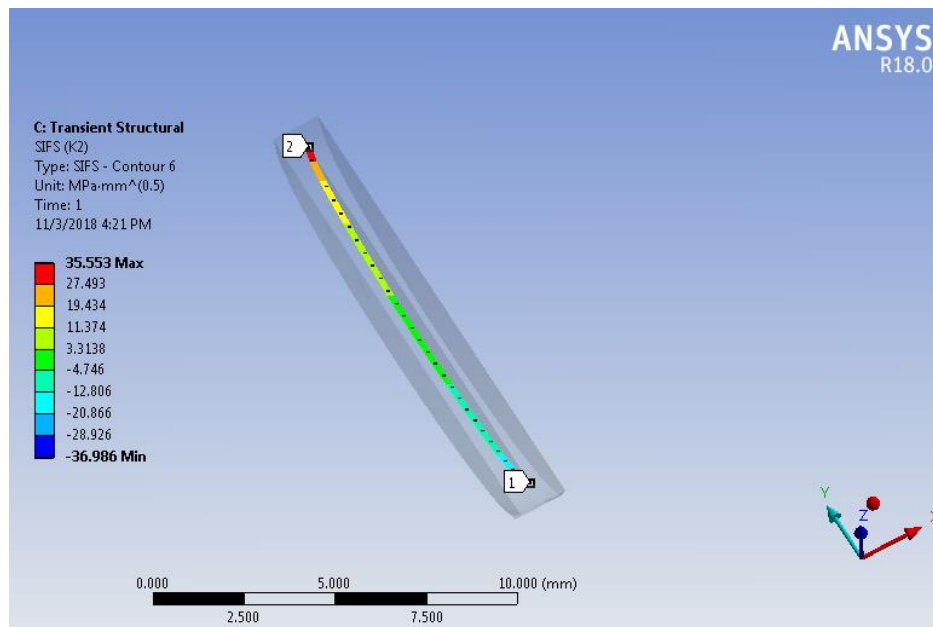


Fig 8.7.14 Stress Intensity Factor K2 analysis

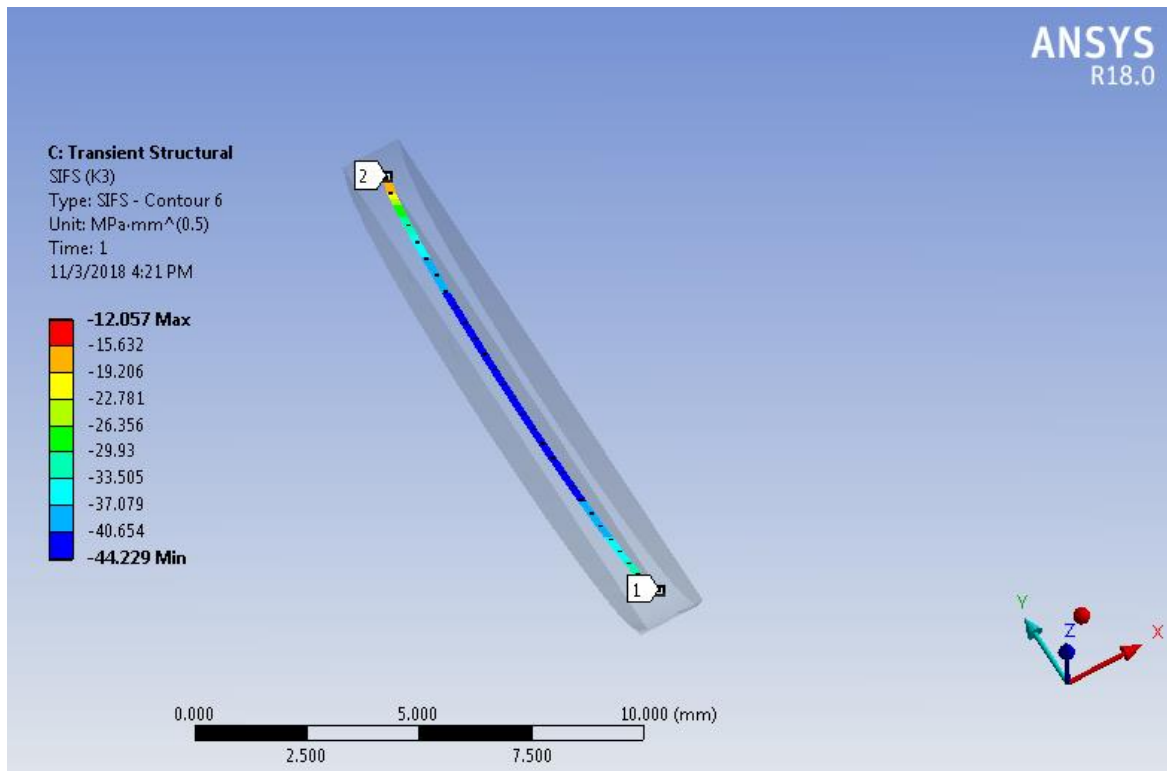


Fig 8.7.15 Stress Intensity Factor K3 analysis

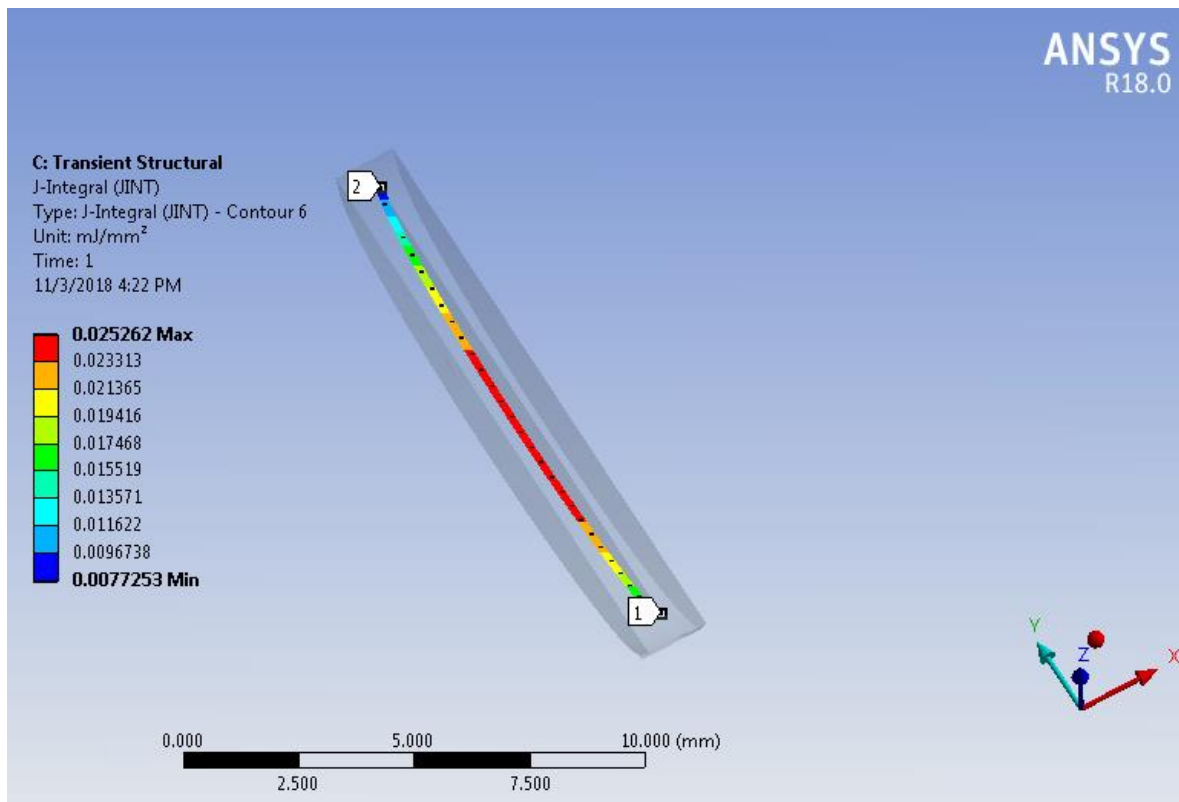


Fig 8.7.16 J-Integral Factor analysis

8.7.5 Crack 5:

For crack 5, major radius selected for the semi-elliptical crack is 7mm and minor radius selected is 1.5mm. The Analysis results for three modes of Stress Intensity factors i.e. K1, K2, K3 and J-Integral evaluation is shown.

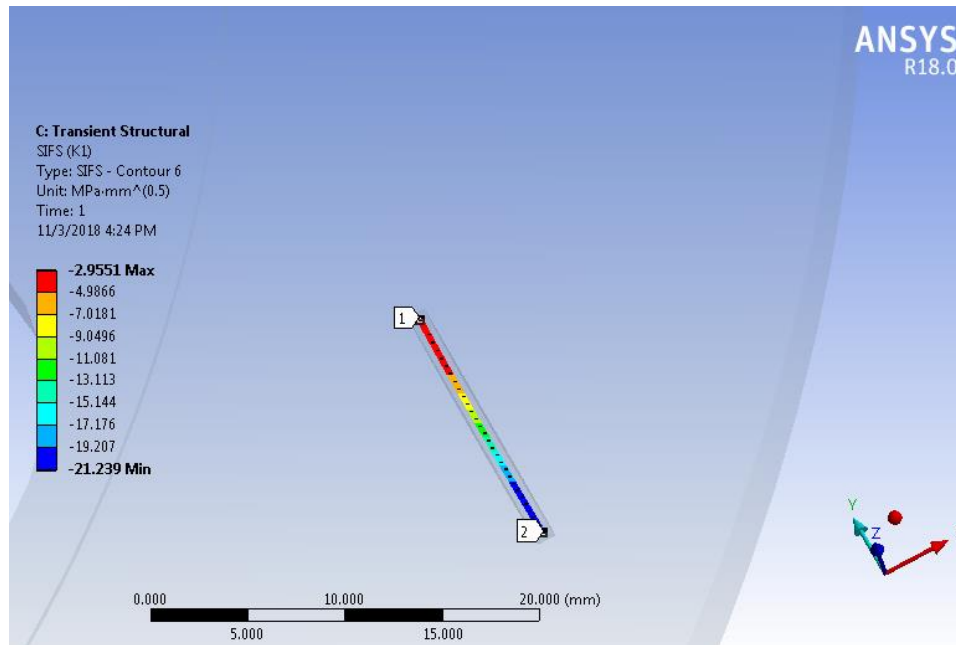


Fig 8.7.17 Stress Intensity Factor K1 analysis

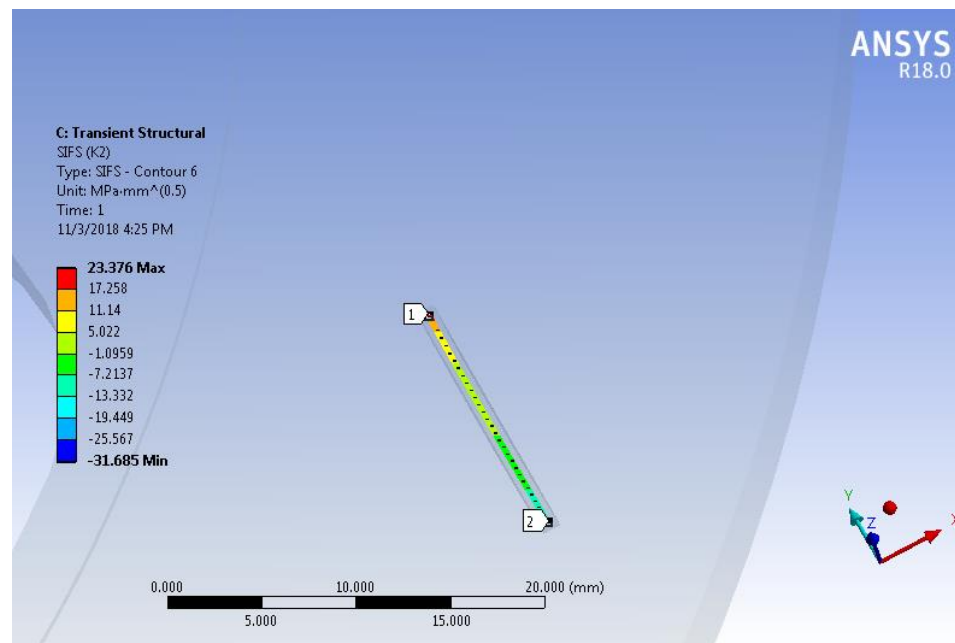


Fig 8.7.18 Stress Intensity Factor K2 analysis

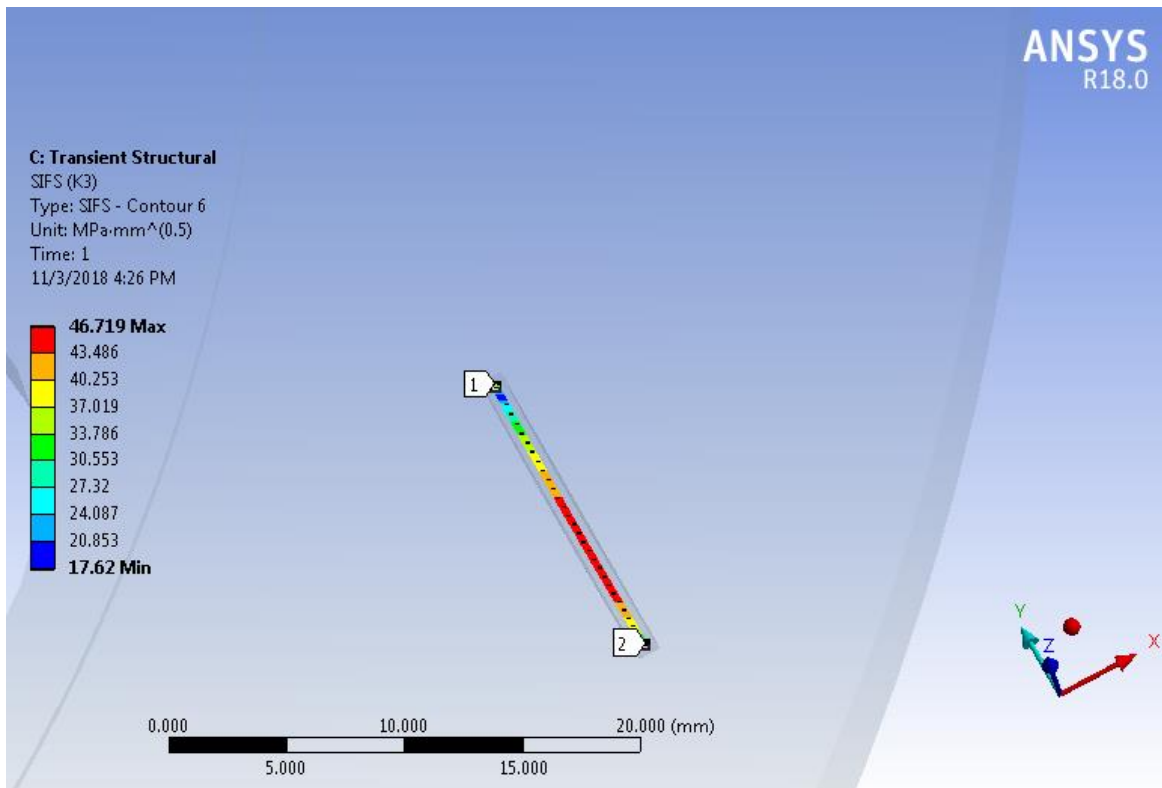


Fig 8.7.19 Stress Intensity Factor K3 analysis

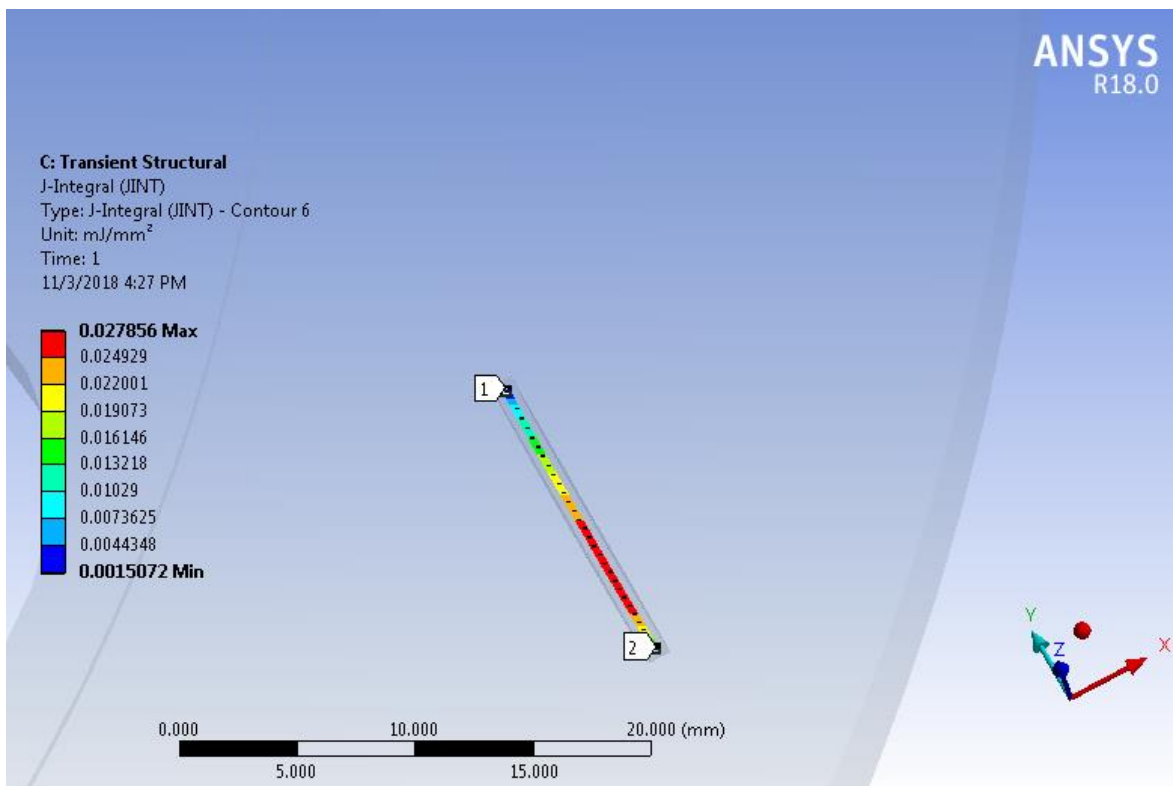


Fig 8.7.20 J-Integral Factor analysis

Chapter 9

Results & Conclusions

9.1 Results

Result table from above analysis is shown below

Cracks	SIF Mode 1 (K1)	SIF Mode 2 (K2)	SIF Mode 3 (K3)	J-Integral
Crack 1	18.16	4.3	5.622	0.0028953
Crack 2	28.438	20	5.6221	0.0028953
Crack 3	-45.213	34.419	55.424	0.088982
Crack 4	-3.3327	35.553	-12.057	0.025262
Crack 5	-2.9551	23.376	46.719	0.027856

9.2 Conclusion

- A study was conducted on a Bajaj Pulsar 150cc Disc brake where we found that due to tremendous increase in temperature for a certain interval of time, there exists a sudden expansion and contraction in the disc material which leads to fatigue of the disc material.
- To study this cause a standard CAD model was prepared by using Solidworks with reference dimensions taken from research paper.
- A Steady-State Thermal Analysis was performed in ANSYS Workbench with boundary conditions stated. After which a Transient Structural Analysis was performed with randomly spotted semi-elliptical cracks of different dimensions.
- SIF Factor (K1, K2, K3) and J-Integral is evaluated from analysis and by comparing it with standard values of Gray Cast Iron we concluded that given disc brake may initiate cracks but due to its less size it may be neglected from cracks under these conditions.
- By analysis results we can conclude that for crack 1 and crack 2, there is higher value of K1 Factor being 18.16 & 28.438 and these falls under the standard limits hence they can be neglected. Also, J-integral value are 0.0028953 & 0.0028953 hence, mode I type cracks may initiate but due to its neglected size and closure value to its standard value it can be neglected.
- Also Crack 3 and crack 5 has more chances of achieving Mode III type crack due to higher value of K3 factor and no Mode I cracks because of its negative value. And since its J-integral value is very less being 0.088982 and 0.027856 these cracks can be neglected.
- For Crack 4, the highest value is for K2 being 35.553 Mode II type failure may initiate but J-integral value being 0.025262 these cracks can be neglected. No mode I type will be initiated due to its negative value.

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