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# Efficient Shape and Material for Performance Disc Brake by Coupled Structural & Thermal Analysis

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**Abstract:** ***The ever increasing need of effective transportations puts automobile manufacturers in a non-avoidable situation of maintaining and improvement of safety systems. The brake system has always been one of the most critical active safety systems. Brake cooling is further an important aspect to consider for brake disc durability and performance. The motive of undertaking this project of "Efficient Shape and Material for Disc Brake by coupled Structural & Thermal Analysis" is to study and evaluate the performance under severe braking conditions and there by assist in disc rotor shape and material. ANSYS package is a dedicated finite element package used for determining the temperature distribution, variation of stresses and deformation across the disc brake profile. In the present work, two shapes of discs available in the market for 180c.c motor cycles are considered and are individually analyzed with Grey Cast Iron and carbon Ceramic as material to determine structural deformation and stress coupled with transient thermal analysis .Based on the above results, efficient shape and material of disc is suggested.***

**Keywords:** CATIA, ANSYS, Disc brake, Heat flux, Heat transfer coefficient, Structural analysis, Transient thermal analysis.

## 1. Introduction

### 1.1 Introduction

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of the member. In the process of performing this function, the brakes absorb either kinetic energy of the moving member and convert it into heat energy, which is dissipated to the surrounding atmosphere.

### 1.2 Working Principle

When brakes are applied, hydraulically actuated pistons move the friction pads in to contact with the disc, applying equal and opposite forces on the later. Upon releasing the brakes, the rubber-sealing ring acts as return spring and retracts the pistons and the friction pads away from the disc.

The main components of the disc brake are:
- The brake Rotor
- The caliper, which contains the piston
- The brake pads

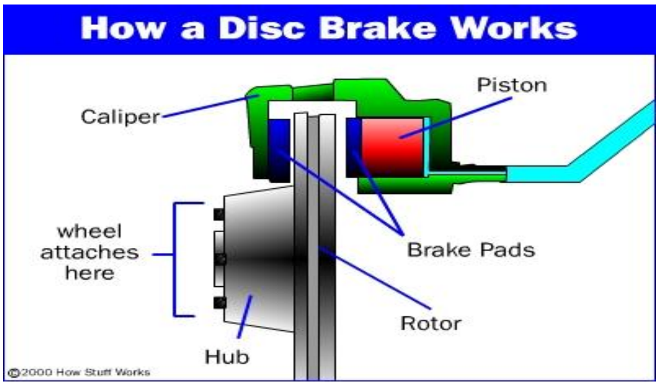


**Figure 1:** Working principle of disc brake

### 1.3 Disc brake considerations:

The braking power of the disc brake mostly depends on the following reasons. They are:
- *Diameter of Rotor*: Larger diameter rotors have more brake power for the same clamping force.
- *coefficient of friction*: The more the coefficient of friction at the interface, the more is the brake power.
- *Material for brake rotor*: The thermal diffusivity of brake rotor should be high to maintain less temperature of brake rotor.
- *Speed sensitivity*: As the sliding velocity between rotor and pad increases, coefficient of friction decreases, so brake power decreases.
- *Pressure sensitivity*: The more the clamping pressure, the more is the coefficient of friction, so the brake power increases.
- *Temperature sensitivity*: As the temperature of brake rotor increases, the coefficient of friction decreases, so the brake power decreases.
- *Contact area of brake rotor:* The more the surface area, the better would be the heat dissipation, so the brake power increases.

### 1.4 Objective of the Project

The objective is to model two Disc brakes using CATIA V5 and carry out the finite element analysis (FEA) on the prepared models using ANSYS 16. The investigation is aimed to study the efficient shape of disc brake available in the market for 180c.c motorcycles by simulating them with real braking conditions in ANSYS to find the temperature distribution, deformation and induced stresses. Later the material is changed to carbon ceramic to find out if it is any better compared to conventional grey cast iron.

**Figure 2:** Circular disc brake

**Figure 3:** Petal disc brake.

## 2. Design and Calculation

### 2.1 Disc Design Parameters

**Table 1:** Geometrical dimensions and considerations

| Item | Circular disc | Petal disc |
|---|---|---|
| Disc diameter | 260 mm | 270 mm |
| Disc thickness | 5 mm | 5 mm |
| Mass of disc | 1 kg | 1 kg |
| Effective radius, $R_e$ | 125 mm | 129 mm |
| Nature of holes | Circular | Rectangular |
| No. of attachments | 5 | 6 |
| Weight of automobile (kerb | 145 kg | 139 kg |
| Weight of rider | 65 kg | 65 kg |
| Speed during braking | 80 kmph | 80 kmph |
| Tyre size | 90/90-R17" | 90/90-R17" |

### 2.2 Nomenclature

$F_l$ = Force at brake lever (N)
$D_p$ = Diameter of piston (m)
$A_p$ = Cross Sectional area of piston ($m^2$)
P = Pressure (Pa)
$D_c$ = Caliper piston diameter (m)
$A_c$ = Area of caliper piston ($m^2$)
$F_c$ = Force at caliper piston (N)
μ = Coefficient of friction
$R_e$ = Effective radius (m)
$T_b$ = Braking torque (N-m)
$A_r$ = Area of rubbing faces ($m^2$)
q = Heat flux ($w/m^2$)
α = Coefficient of thermal expansion ($k^{-1}$)
κ = Thermal conductivity ($WM^{-1}K^{-1}$)
h = Heat transfer coefficient ($WM^{-2}K^{-1}$)
Nu = Nusselt number
Re = Reynolds number
Pr = Prandtl number
ρ = Density (Kg $m^{-3}$)
υ = Poisson ratio
E = Youngs Modulus (Mpa)

### 2.3 Material Property

For analysis we have considered **Grey cast iron** and **Carbon ceramic**

**Table 2:** Material properties

| **Property** | Carbon ceramic | Grey cast iron |
|---|---|---|
| Density | 2450 $kgm^{-3}$ | 7250 $kgm^{-3}$ |
| Tensile strength | 40 Mpa | 250 Mpa |
| Youngs Modulus | 30 Gpa | 110 Gpa |
| Poisson ratio | 0.3 | 0.22 |
| Thermal stability | 1350 $^{o}$c | 700 $^{o}$c |
| Coefficient of thermal expansion | $3x10^{-6}$ $K^{-1}$ | $1.1x10^{-5}$ $k^{-1}$ |
| Thermal conductivity | 40 $wm^{-1}k^{-1}$ | 54 $wm^{-1}k^{-1}$ |
| Specific heat | 800 $jkg^{-1}k^{-1}$ | 500 $jkg^{-1}k^{-1}$ |

### 2.4 Calculations

#### 2.4.1 For Circular Disc brake:

1. Force at brake lever, $F_l$ = 20/40N.
   20N is during normal braking and 40N during panic braking. We consider average of 30N.
2. Pedal ratio/leverage ratio = 5:1
3. Braking effort = 5*30N = 150N
4. Diameter of piston, $D_p$ = 7mm
   Area of piston, $A_p = \pi/4 * D_p * D_p$
   $= 3.84x10^{-5}$ $m^2$
5. Fluid pressure, P = F/$A_p$
   = 3899649 Pa
   As per PACALS LAW the same pressure is exerted at caliper and from the obtained pressure, the force at the caliper piston can be calculated. From the caliper force (Fc), the braking torque is calculated.
6. Diameter of caliper piston, $D_c$ = 30mm
   Area of caliper piston, $A_c = \pi/4 * D_c * D_c$
   $= 7x10^{-4}$ $m^2$
7. Force at caliper piston, $F_c = P*A_c$
   = 2755 N
8. Total frictional force, N = 2*μ* $F_c$
   = 2589 N
   Effective radius, $R_e$ = 0.125 m
9. Braking torque, $T_b$ = N*$R_e$
   = 320 N-m
10. Velocity of vehicle = 80kmph = 22.2 mps
    Laden weight of vehicle = 200kg
    Kinetic Energy of vehicle = 0.5*200* $22.2^2$
    = 49284 J
    Braking ratio, Front: Rear = 80: 20
    Braking KE at front wheel = 49284*0.8
    = 39427 N
11. Total area of rubbing faces, $A_r$ = 0.0364 $m^2$
12. Time of braking to reach 0 kmph = 4 s
13. Heat flux, q = KE/Time/$A_r$
    = 39427/4/0.0364
    = 273798 $w/m^2$

#### 2.4.2 For Petal Disc brake

1. Force at brake lever, $F_l$ = 20/40N.
   20N is during normal braking and 40N during panic

braking. We consider average of 30N.

2. Pedal ratio/leverage ratio = 5:1
3. Braking effort = 5*30N = 150N
4. Diameter of piston, $D_p$ = 7mm
   Area of piston, $A_p = \pi/4 * D_p * D_p$
   $= 3.84 \times 10^{-5}\ m^2$
5. Fluid pressure, $P = F/A_p$
   = 3899649 Pa

   As per PACALS LAW the same pressure is exerted at caliper and from the obtained pressure, the force at the caliper piston can be calculated. From the caliper force (Fc), the braking torque is calculated.
6. Diameter of caliper piston, $D_c$ = 33mm
   Area of caliper piston, $A_c = \pi/4 * D_c * D_c$
   $= 8.5 \times 10^{-4}\ m^2$
7. Force at caliper piston, $F_c = P * A_c$
   = 3333 N
8. Total frictional force, $N = 2 * \mu * F_c$
   = 3133 N

   Effective radius, $R_e$ = 0.130 m
9. Braking torque, $T_b = N * R_e$
   = 407 N-m
10. Velocity of vehicle = 80kmph = 22.2 mps
    Laden weight of vehicle = 200kg
    Kinetic Energy of vehicle = $0.5*200*22.2^2$
    = 49284 J
    Braking ratio, Front: Rear = 80: 20
    Braking KE at front wheel = 49284*0.8
    = 39427 N
11. Total area of rubbing faces, $A_r = 0.033\ m^2$
12. Time of braking to reach 0 kmph = 4 s
13. Heat flux, $q = KE/Time/A_r$
    = 39427/4/0.033
    $= 298689\ w/m^2$

**2.4.3 To find out heat transfer coefficient:**

For turbulent flow over a flat plate, the relation between nusselt number, reynolds number and prantyl number is given as:

$$\mathbf{Nu_L = 0.037\ Re^{0.8}\ Pr^{0.33}} \qquad (1)$$

$hL/K = 0.037\ (\rho vL/\mu)^{0.8}\ (\mu c_p/K)^{0.33}$

$h = 0.037K/L\ (\rho vL/\mu)^{0.8}\ (\mu c_p/K)^{0.33}$

$= 98\ WM^{-2}K^{-1}$

## 3. Methodology

### 3.1 Modeling in CATIA

CATIA software is the standard in the 3D product design, featuring industry-leading productivity tools that promote one of the best practices in design while ensuring compliance regarding industry and company standards. The designing of CATIA solution allow you to design you faster than any other software. The figure shows the solid model of the disc brake by using CATIA. By taking the circular and petal disc brake dimensions we have to draw the disc brake model in CATIA.

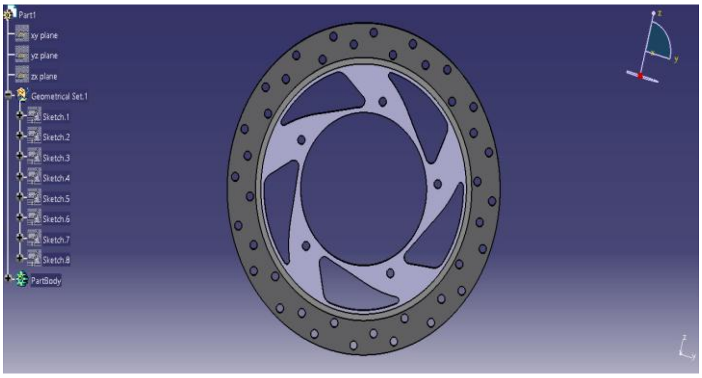


**Figure 4:** Circular disc brake rotor model in CATIA

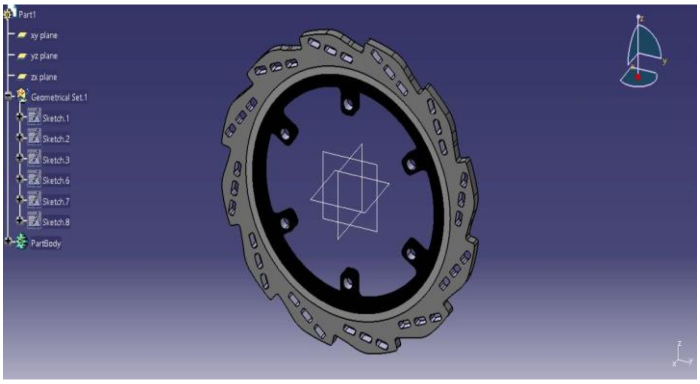


**Figure 5:** Petal disc brake rotor model in CATIA

The above shown figure is model drawn in the CATIA software are by using the exact Dimensions of the Disc Brake rotors with correct thickness and Dimensions.

### 3.2 Analysis in ANSYS:

Dr. John Swanson founded ANSYS Inc in 1970 with a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEM). The software implements the equations that govern the behavior of these elements and solve the problems, by creating comprehensive explanation of how the acts as whole. The results can be obtained in the form of tabular column or graphical forms.

### 3.2.1 Static structural Analysis:

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects such as those caused by time varying loads. A static analysis can, however include steady inertia loads such as gravity and rotational velocity.

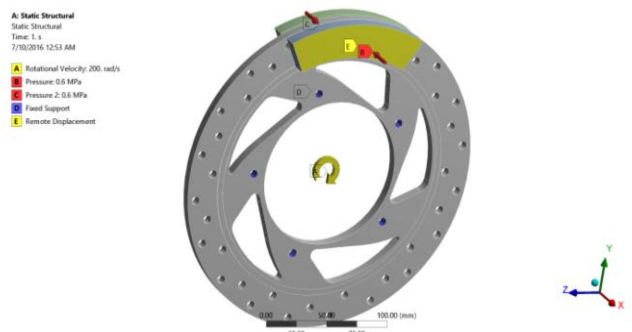


**Figure 6:** Structural conditions on circular disc rotor

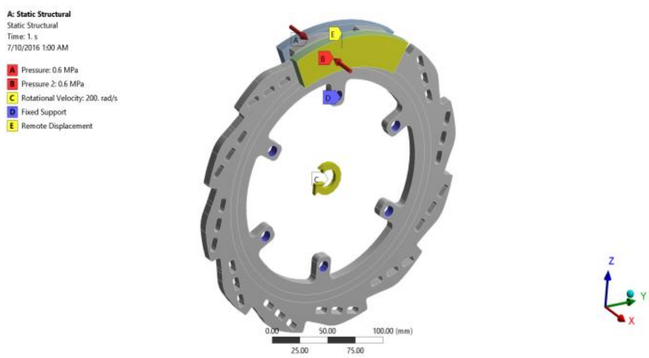


**Figure 7:** Structural conditions on petal disc rotor

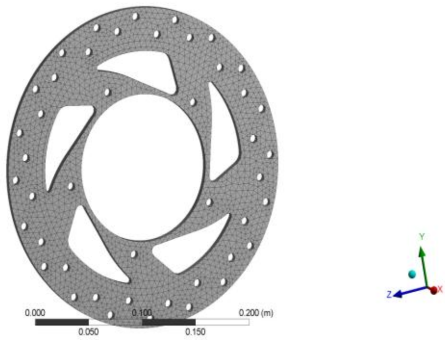

**Figure 8:** Meshed model of circular disc brake

Figure 8 shows the meshed model of disc brake for structural analysis process. For analysis circular disc brake was meshed using triangular surface mesher. The number of Nodes used in this meshing is 40977 and elements are 22844.

### 3.2.2 Thermal analysis

A Thermal analysis calculates the temperature distribution and related thermal quantities in a system or component.
Typical thermal quantities are:
1. The temperature distributions.
2. The amount of heat lost or gained.
3. Thermal fluxes.

Types of thermal analysis:
1. A **Steady State Thermal** Analysis determines the temperature distribution and other thermal quantities under steady state loading conditions. A steady state loading condition is a situation where heat storage effects varying over a period of time can be ignored.
2. A **Transient Thermal** analysis determines the temperature distribution and other thermal quantities under conditions that vary over a period of time.

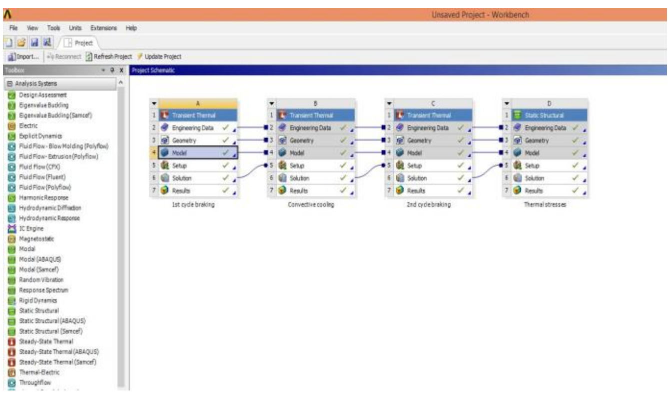

**Figure 9:** Thermal analysis coupled structural analysis

## Results

### 4.1 Structural Results

The Equivalent von-Mises stress analysis and total deformations for both grey cast iron and carbon ceramic discs are shown below:

### 4.1.1 For grey cast iron

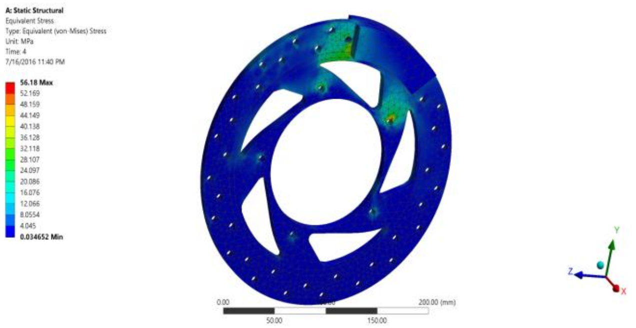

**Figure 10:** Stress distribution in circular disc

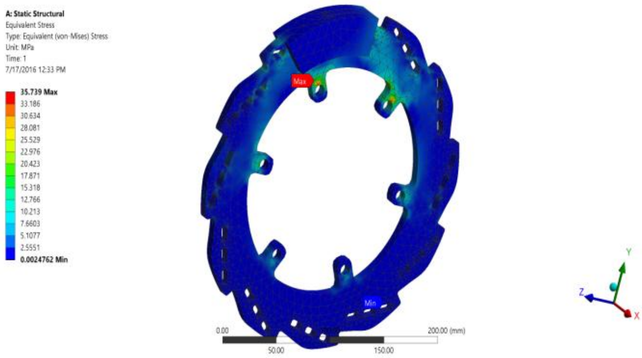

**Figure 11:** Stress distribution in petal disc

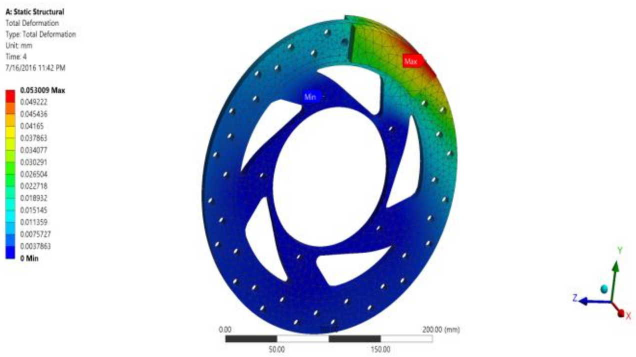

**Figure 12:** Total deformation in circular disc

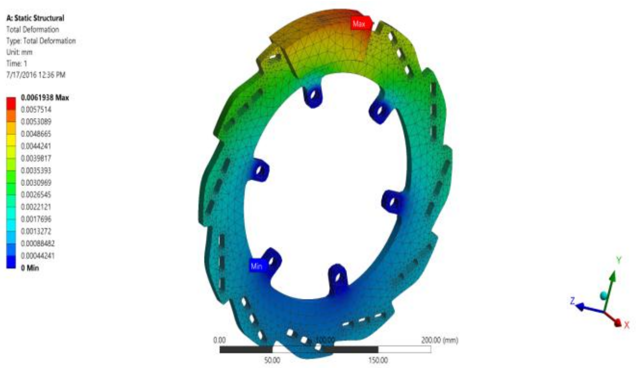

**Figure 13:** Total deformation in petal disc

#### 4.1.2 For carbon ceramic

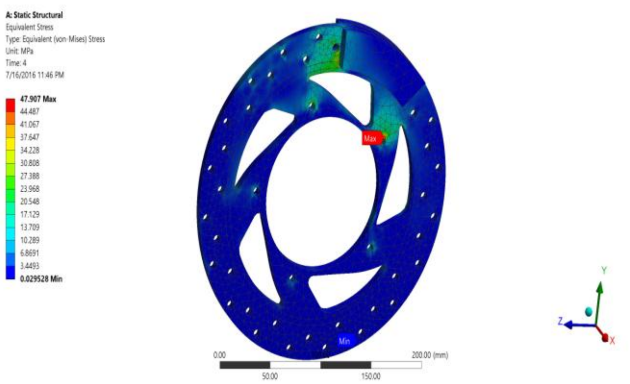

**Figure 14:** Stress distribution in circular disc

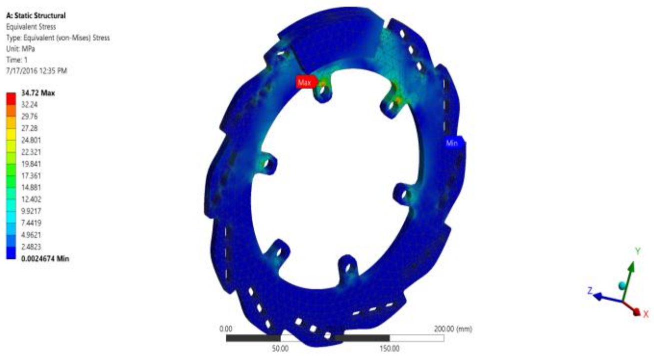

**Figure 15:** Stress distribution in petal disc

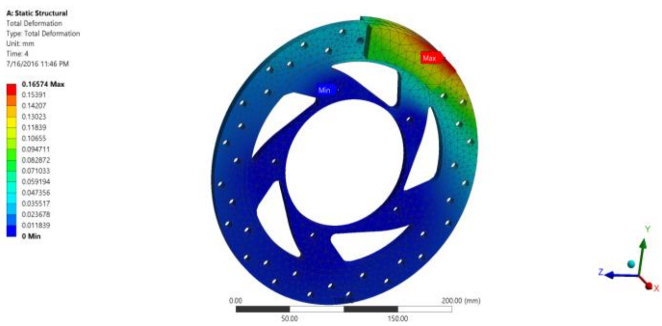

**Figure 16:** Total deformation in circular disc

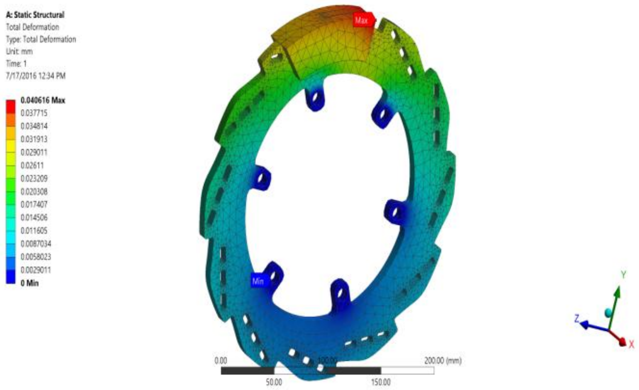

**Figure 17:** Total deformation in petal disc

### 4.2 Thermal Results coupled to structural analysis

A steady state thermal Analysis also calculates the temperature distribution & other thermal related quantities in rotor disc under steady state loading conditions. A steady state loading condition is a situation where heat storage effects varying over a period of time can be ignored. For thermal analysis we have calculated the following values & find out Heat Flux during 4 sec of braking.

#### 4.2.1For grey cast iron

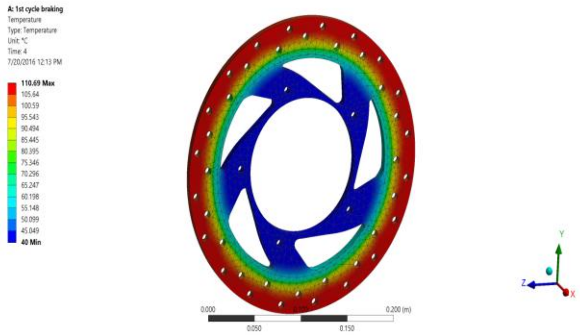

**Figure 18:** Temp. in circular Disc for first cycle braking

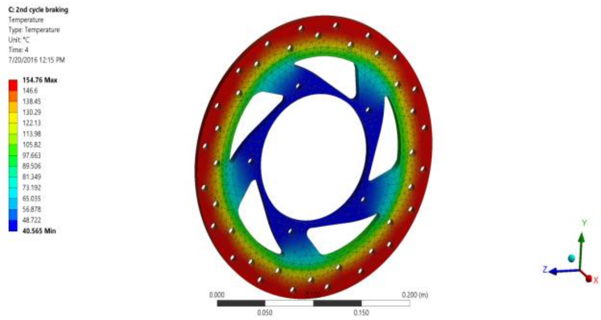

**Figure 19:** Temp. in circular disc for 2nd cycle braking

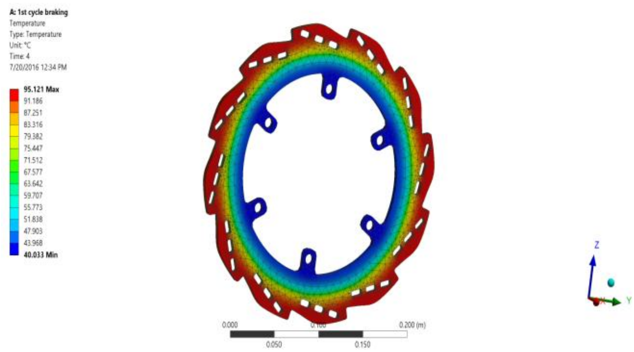

**Figure 20:** Temp. in petal disc for 1st cycle braking

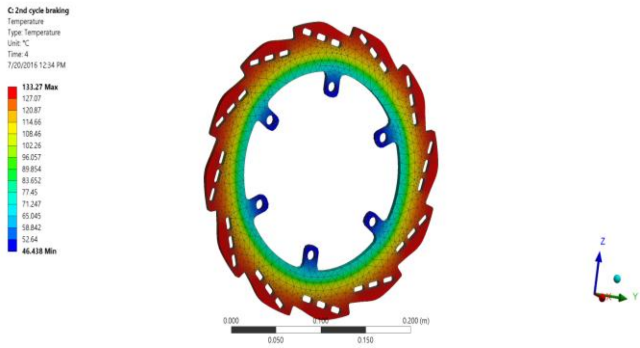

**Figure 21:** Temp. in petal disc for 2nd cycle braking

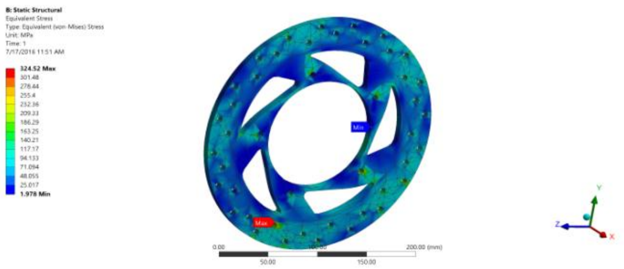

**Figure 22:** Thermal stress in circular disc

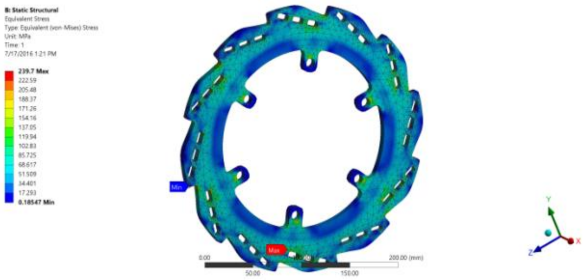

**Figure 23:** Thermal stress in petal disc brake

### 4.2.2 For carbon ceramic

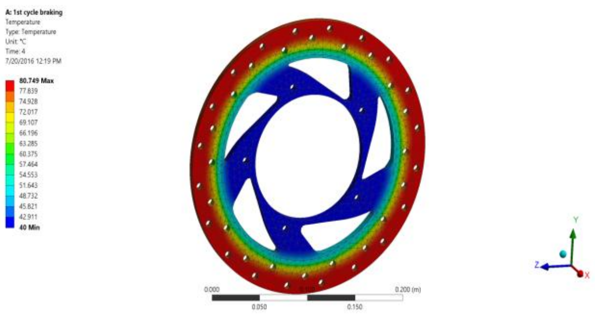

**Figure 24:** Temp. in circular disc for first cycle braking

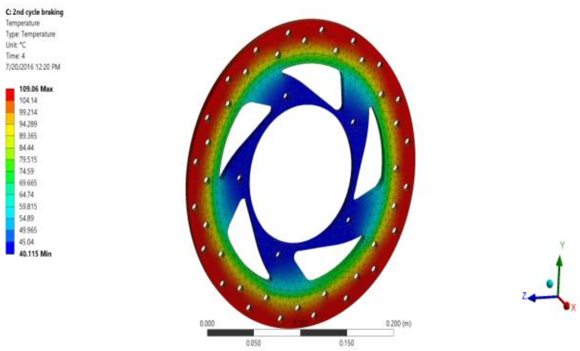

**Figure 25:**Temp. in circular disc for 2nd cycle braking

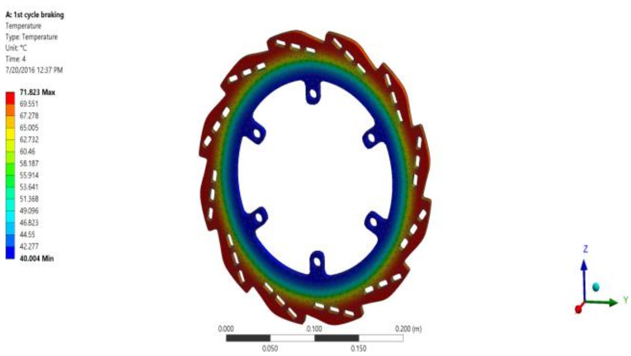

**Figure 26:**Temp. in petal disc for 1st cycle braking

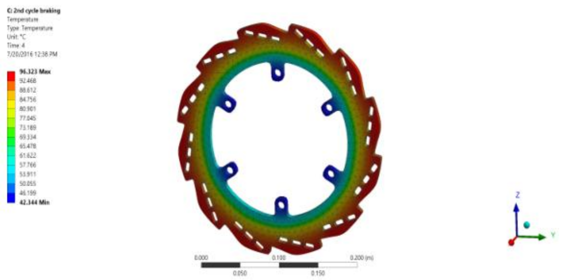

**Figure 27:**Temp. in petal disc for 2nd cycle braking

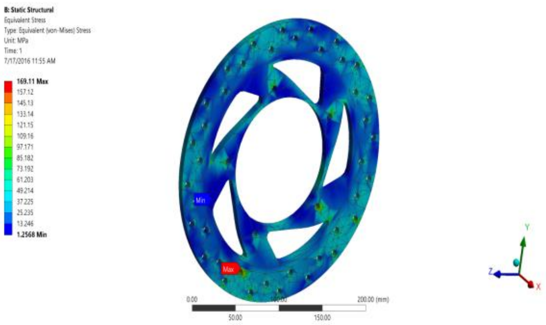

**Figure 28:** Thermal stress in circular disc

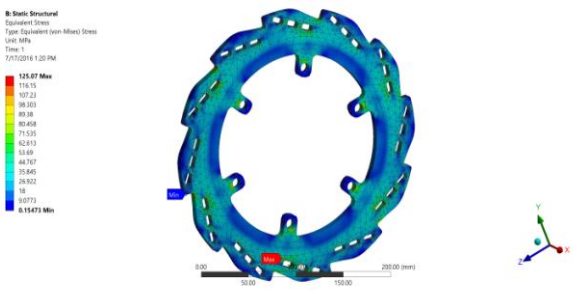

**Figure 29:** Thermal stress in petal disc

**Table 3:** Static structural results

| | Static Structural | |
|---|---|---|
| | Stress, Mpa | Deformation, mm |
| Disc GCI | 56 | 0.05 |
| Petal GCI | 35.73 | 0.00619 |
| Disc CC | 47.9 | 0.16574 |
| Petal CC | 34.7 | 0.040 |

**Table 4:** Transient Thermal coupled structural results

| | Transient Thermal coupled structural | | |
|---|---|---|---|
| | Stress, Mpa | Deformation,mm | Max Temperature, °c |
| Disc GCI | 324 | 0.06 | 154.7 |
| Petal GCI | 239.7 | 0.01 | 133.27 |
| DISC CC | 169 | 0.02 | 109 |
| Petal CC | 125 | 0.044 | 96.32 |

## Conclusion

From the Results obtained above, we can conclude that:

1) Petal disc has good braking performance than circular disc brake.

2) The deformation and stress accumulation are very low in petal disc to circular disc.
3) Although it is a bit costly to use Carbon ceramic brake instead, the stress and braking temperature are very low than conventionally used grey cast iron.
4) Stress accumulated on the carbon ceramic is much less, which proves good wear resistance, rigid and stable braking during high speeds.

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