# Coupled Thermal-Static Analysis and Topology Optimization of FSAE Brake Disc

**Srujan Tikekar**[1]

[1]*Srujan Tikekar, Student, Dept. of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune, Maharashtra, India*

***

**Abstract -** *To design a reliable and optimized FSAE(Formula Society of Automotive Engineers) brake disk for better performance and life is the goal of this paper. The main purpose of this study is to analyze the Thermo-mechanical behavior of the brake disc, during the braking phase. The designing of the disc was performed by using DS SOLIDWORKS 2018 and to carry out analysis of various physical quantities ANSYS STUDENT 2021 R1 was used. GREY CAST IRON was used in the designing of the brake disc. By using coupled analysis and topology optimization, the final design of brake disc was concluded to be durable, light-weight and was having a better thermal as well as structural performance than the original one.*

***Key Words***: **Coupled analysis, brake disc, cast iron, optimization, FSAE, weight reduction**

## 1. INTRODUCTION

A brake system is designed to slow and halt the motion of vehicle. To do this, various components within the brake system must convert vehicle's moving energy into heat. This is done by using friction. Friction is the resistance to movement exerted by two objects on each other. A disc brake is a type of brake that uses the callipers to squeeze pairs of pads against a disc or a rotor to create friction. This action slows the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. Hydraulically actuated disc brakes are the most used form of brake for motor vehicles, but the principles of a disc brake are applicable to almost any rotating shaft. The components include the disc, master cylinder, calliper (which contains cylinder and two brake pads) on both side of the disc. Disc brakes are used in FSAE cars. Proper performance of the braking system by following the protocol of the FSAE cars of high speed is one of its advantages. The mass of any vehicle requires energy to accelerate or decelerate. Reducing vehicle mass improves acceleration and requires less energy to be dissipated during deceleration. Rotating mass requires additional energy to increase or decrease its speed of rotation. Therefore, decreasing the mass of the disc has greater benefit since the disc must rotate as well.

## 2.LITERATURE REVIEW

Thermal analysis is a general term defining a technique used to analyze the time and temperature at which physical changes occur when a substance is heated or cooled. A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Topology optimization is a mathematical method which spatially optimizes the distribution of material within a defined domain, by fulfilling given constraints previously established and minimizing a predefined cost function. For such an optimization procedure, the three main elements are design variables, the cost function, and the constraints. Sometimes the designs generated by topology optimization are in accordance with performance but difficult to manufacture and hence necessary design changes are made during the design process considering the manufacturing aspect.

## 3.BEGINNING WITH ALREADY OPTIMIZED DISC:

**Fig 1:** Flow Chart of the process

### 3.1 Initiation:

Firstly a CAD model of the disc was prepared on DS SOLIDWORKS 2018. Figure below shows the initial model. The overall dimensions and the mounting positions were created. Holes were created for better heat dissipation and to reduce weight of the disc. The OD (outer diameter) of the disc is 180mm, inner diameter of 120mm and has a PCD(Pitch Circle Diameter) of 90mm.

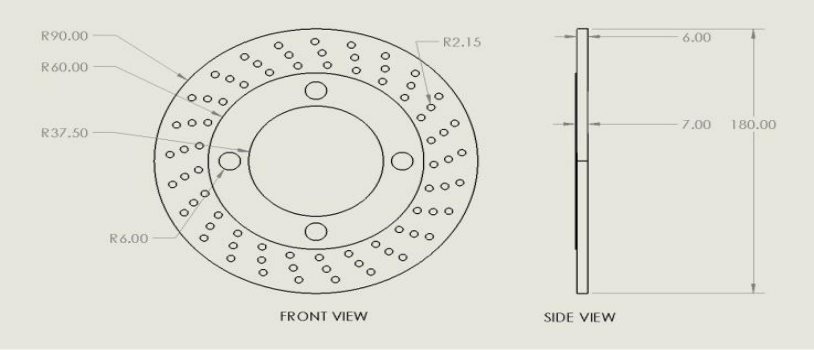


**Fig2:** 2D view of already optimized brake disc of OD=180mm

### 3.2 Calculations:

3.2.1 TABLE OF PARAMETERS:

| SR NO. | PARAMETERS | SYMBOL | VALUE | UNIT |
|---|---|---|---|---|
| 1 | Initial velocity of the vehicle | $v$ | 13.889 | m/s |
| 2 | Input Driver Force | $F_i$ | 350 | N |
| 3 | Pedal Ratio | $b$ | 4 | - |
| 4 | Bore Diameter of Master Cylinder | $d_{mc}$ | 0.01586 | m |
| 5 | Diameter of Caliper Piston | $d_{ca}$ | 0.0254 | m |
| 6 | Area of Master Cylinder | $A_{mc}$ | $1.9746\times10^{-4}$ | $m^2$ |
| 7 | Area of Caliper | $A_{ca}$ | $5.0645\times10^{-4}$ | $m^2$ |
| 8 | Disc Pad Coefficient Friction | $\mu$ | 0.35 | - |
| 9 | Effective Radius of Disc | $r_e$ | 0.090 | m |

3.2.2 FURTHER CALCULATIONS:

1. Force at master cylinder (Fm) = $F_l$ × b =1400 N
2. Pressure (P) = Fm/$A_{mc}$ = 7090043.55 Pa
3. Force at caliper ($F_{ca}$) = P × $A_{ca}$ = 3590.75 N
4. Total Clamping force (Fc) = 2× µ × $F_{ca}$ = 2513.52 N
5. Clamping force on each side = 1256.7634 N
6. Braking Torque (T) = Fc × Re = 113.108 Nm

## 2. ANALYSIS

The disc is now analyzed in the Analysis software. Here we are using the ANSYS STUDENT 2021 R1. Starting with material selection.

### 3.3.1 MATERIAL SELECTION:

The first step after designing of the model was to select the material with which the model has to be analysed and manufactured. GREY CAST IRON was the material selected and assigned to the designed brake disc.

MATERIAL: GRAY CAST IRON

| PROPERTIES | VALUES | UNIT |
|---|---|---|
| DENSITY | 7200 | Kg/m3 |
| YOUNG'S MODULUS | 1.1×1011 | Pa |
| THERMAL CONDUCTIVITY | 52 | W/m·°C |
| SPECIFIC HEAT | 447 | J/kg·°C |
| TENSILE ULTIMATE STRENGTH | 2.4×108 | Pa |

### 3.3.2 MESHING:

Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into discrete geometric and topological cells. Usually the cells partition the geometric input domain. Mesh cells are used as discrete local approximations of the larger domain.

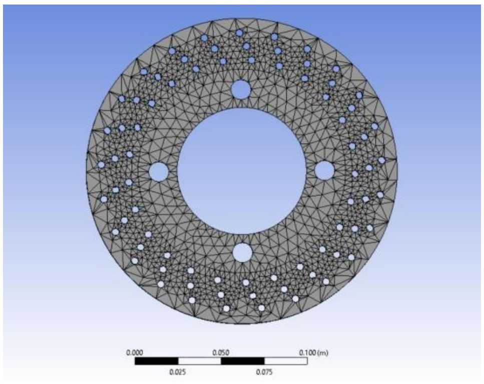


**Fig 3:** Meshing of the brake disc

### 3.3.3: COUPLED THERMAL-STATIC ANALYSIS:

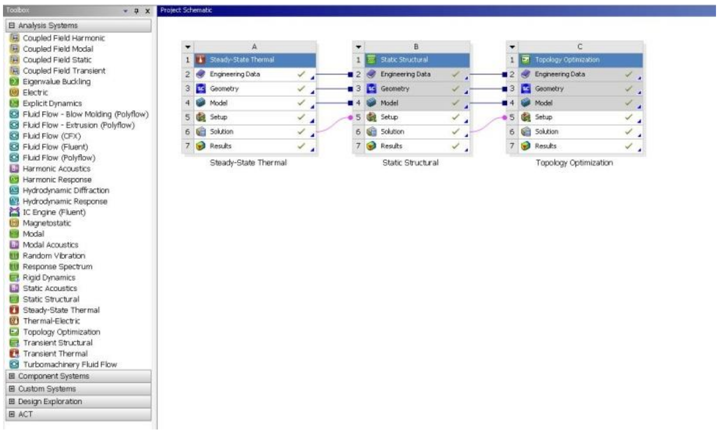


**Fig4:** Coupled thermal-static analysis and topology optimization

A coupled thermal-static analysis was performed on the disc. The results obtained from the steady-state thermal analysis were loaded into static structural analysis. Thus, after combining outputs of both the results we got our desired goal.

### 3.3.3.1 STEADY-STATE THERMAL ANLYSIS:

1) <u>TEMPERATURE:</u>

After loading the model in ANSYS Workbench and opening the model in steady-state thermal, a temperature of 70°C was applied on the outer most part of the brake disc (both the faces) where the brake caliper would be mounted as shown in Fig 5.

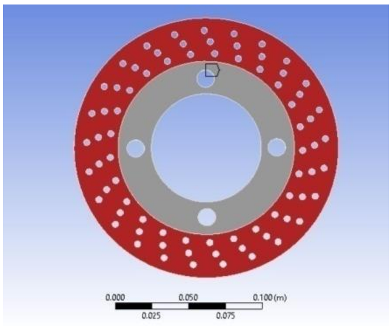


**Fig 5:** Applying temperature

2) <u>CONVECTION:</u>

The heat generated due to friction between brake pads and caliper is majorly dissipated through the inner part of the brake disc to the surrounding (air) Shown in Fig 6 below.

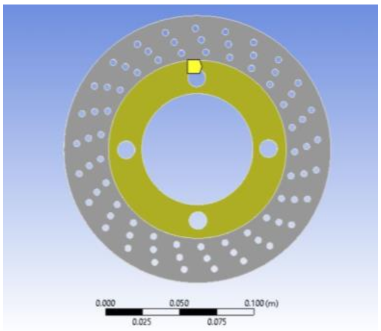


**Fig 6:** Applying convection

### 3.3.3.2 STATICSTRUCTURAL:

1) ROTATIONAL VELOCITY:

After loading the output values from thermal analysis to static structural, the first thing that was applied on the disc was rotational velocity. As the torque is transmitted to the axle, along with the wheel hub, disc also revolves. Thus, rotational velocity is applied to the inner part.

$v = r \times \omega$

$\omega = v/r = 13.889/0.090 = 154.3$ rad/s

Hence, a rotational velocity of 154.3 rad/s was applied to the disc at the initial stage in clockwise direction.

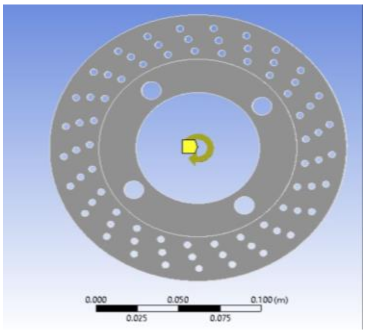


**Fig 7:** applying rotational velocity

2) FIXED SUPPORTS:

The brake disc is bolted to the knuckle of the wheel. Hence a fixed support is applied on the inner holes (4) of the disc as shown in Fig 8.

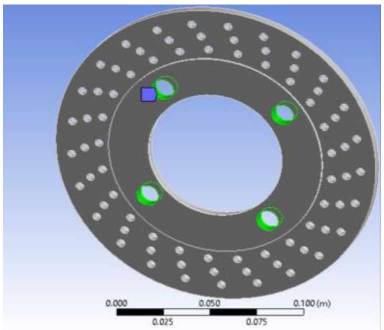


**Fig 8:** fixed supports

3) CLAMPING FORCE:

Perpendicular force would be acting on the outer regions of the brake disc because of the contraction of the brake pads (clamped in caliper) on both sides. A clamping force of 1256.7634 N is applied on both sides of the brake disc.

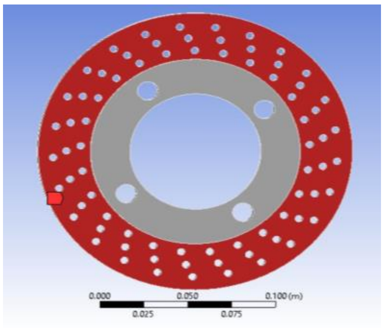


**Fig 9:** applying clamping force

### 3.3.4 TOPOLOGY OPTIMIZATION:

Topology optimization, in a simple description is using the physics of the problem combined with the finite element computational method to decide what the optimal shape is for a given design space and set of loads and constraints. Thus, after getting various results from the coupled thermo-mechanical analysis, the output data was loaded for topology optimization.

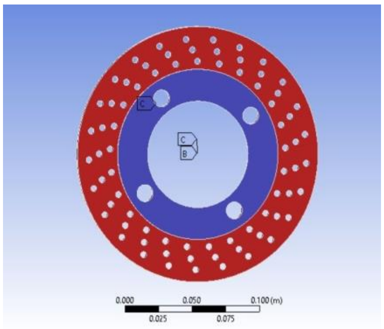
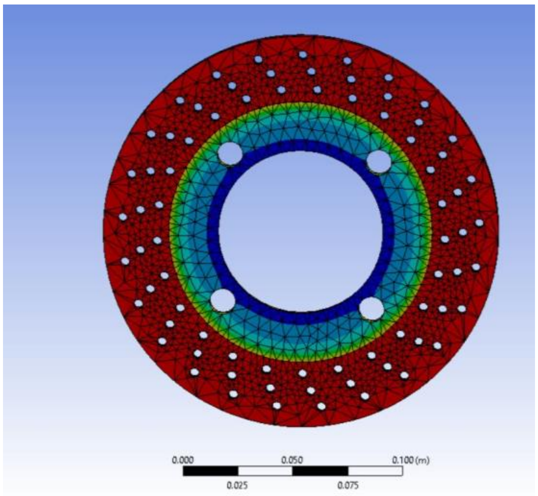


**Fig 10:** topology optimization

## 3.4 RESULTS OF ANALYSIS:

### 3.4.1 OUTPUTS:



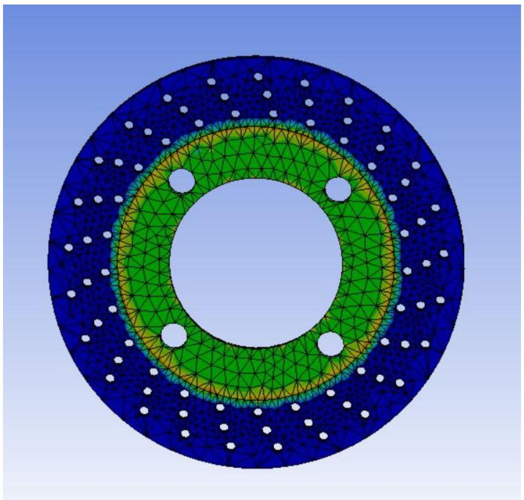
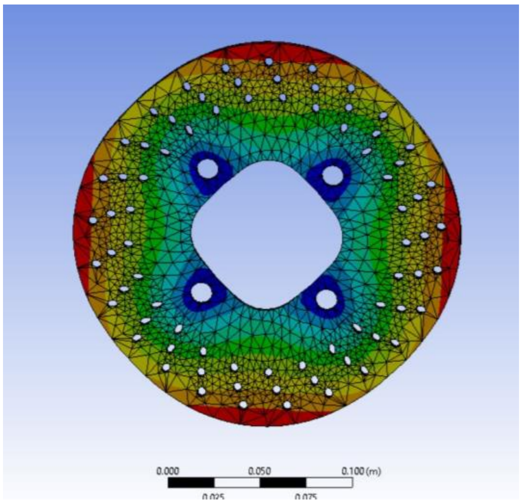


**Fig 11:** temperature of disc **Fig 12:** total heat flux



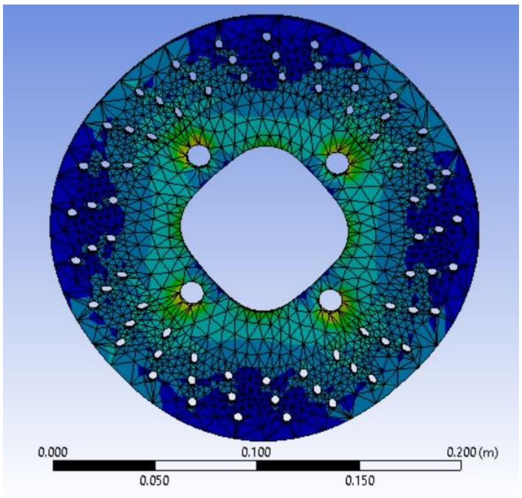
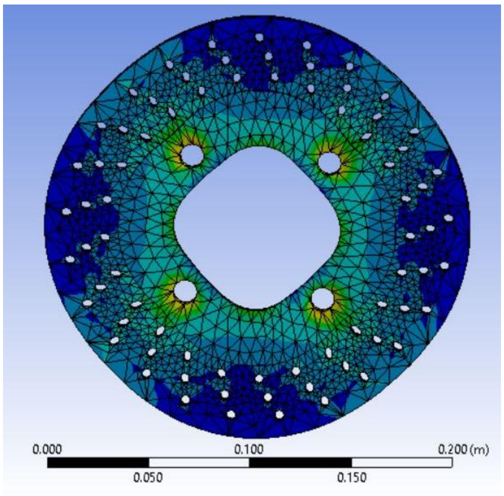


**Fig 13:** total deformation **Fig 14:** equivalent stress



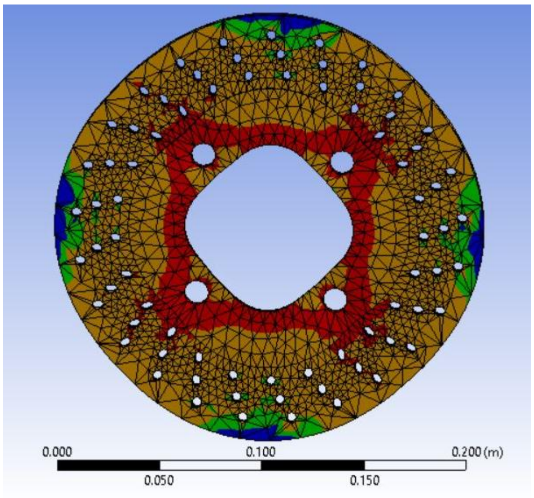


**Fig 15:** equivalent elastic strain **Fig 16:** factor of safety

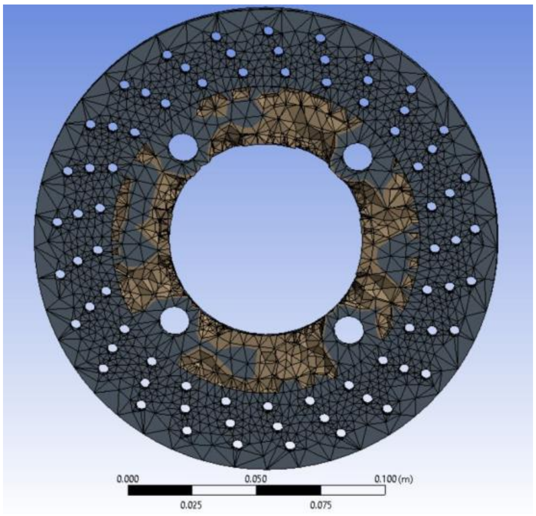


**Fig 17:** topology density

### 3.4.2 RESULT TABLE:

| SR NO.: | RESULT: | MIN VALUE: | MAX VALUE: | AVG VALUE: | UNIT: |
|---|---|---|---|---|---|
| 1 | TEMPERATURE | 69.13 | 70 | 69.9 | oC |
| 2 | HEAT FLUX | 5.439e-007 | 355.85 | 55.635 | W/m2 |
| 3 | TOTAL DEFORMATIONN | 0 | 4.3486e-005 | 2.2461e-005 | m |
| 4 | EQUIVALENT STRESS | 1.1929e+005 | 9.1215e+006 | 6.2913e+006 | Pa |
| 5 | EQUIVALENT ELASTIC STRAIN | 1.069e-005 | 1.578e-003 | 3.3127e-004 | m/m |
| 6 | FACTOR OF SAFETY | 0.27615 | 15. | 2.1373 | - |
| 7 | WEIGHT | - | - | 0.96254 | Kg |

## 4.OPTIMIZATION OF THE DISC:

After performing various operations on the disc and studying the variation of topology density, the disc was optimized. Material was removed from the disc according to the results. To validate the current prepared model, a finite element analysis was done again to make sure that the design is within safety limits.

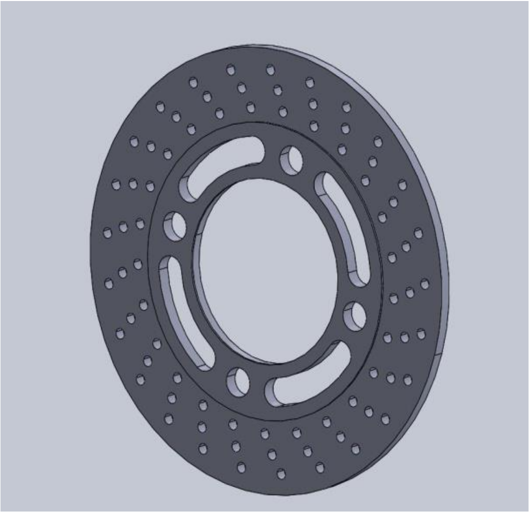


**Fig 18:** optimized disc

## 5. RESULTS FOR OPTIMIZED BRAKE DISC:

| SR NO.: | RESULT: | MIN VALUE: | MAX VALUE: | AVG VALUE: | UNIT: |
|---|---|---|---|---|---|
| 1 | TEMPERATURE | 69.10 | 70 | 69.88 | oC |
| 2 | HEAT FLUX | 2.4996e-006 | 401.55 | 51.016 | W/m2 |
| 3 | TOTAL DEFORMATIONN | 0 | 4.4003e-005 | 2.3443e-005 | m |
| 4 | EQUIVALENT STRESS | 4.3711e+005 | 2.5975e+006 | 6.0748e+006 | Pa |
| 5 | EQUIVALENT ELASTIC STRAIN | 7.8557e-006 | 1.3191e-003 | 3.2584e-004 | m/m |
| 6 | FACTOR OF SAFETY | 0.33185 | 15 | 2.0261 | - |
| 7 | WEIGHT | - | - | 0.7716 | Kg |

Thus, the results show that the disc was successfully optimized within the given safety limits.It is also concluded that the new disc is 19.83% lighter than the previous disc.

## CONCLUSIONS

Thus, the coupled analysis and topology optimization was performed on the brake disc. We analyzed the Thermo-mechanical behavior of the brake disc and studied about the changes a single physical parameter can cause to a brake disc. The optimized brake disc is found to be better than the earlier one. The optimized disc is 19.83% lighter than the earlier disc. The FSAE vehicle requires disc brake which can survive a large variation of thermal and physical values at the time of severe braking. The values obtained from the analysis are in the prescribed value limits for FSAE. Hence the design of the Disc Brake Rotor is safe.
By using this knowledge of topology optimization with engineering aspect an optimized brake disc design can be made in short time.

## REFERENCES

[1] Brake rotor design and comparison using finite element analysis: an investigation in topology optimization 2010 Author(s): Domond, Kenneth.
[2] https://www.cartrade.com/blog/2011/auto-guides/brake-systems-in-cars
[3] https://www.racetechnologies.com/article/how-does-reducing-weight-braking-system-benefit-vehicle
[4] IJMET_09_03_086.pdf
[5] IJRET20160510037.pdf