International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 5, Issue 6, pp 75-81, June-2021

https://doi.org/10.47001/IRJIET/2021.506015

Design Optimization of Disc Brake Using Topology Analysis

[1]Akash Waghmare, [2]Aniket Salvi, [3]Revati Mathpati

[1,2,3]Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, India

***Abstract* – Brake is an essential mechanism in a vehicle because driver can able to control of speed of vehicle, so there is need to have optimal design of disc brakes. Many times, by applying the disc brake large heat is generated in order to protect disc from failure there is need to have an optimal design. In this paper disc design was done through cero 6.0 version however analysis was done through Ansys workbench 2019 student version. The main purpose of writing this paper is to find out optimal design of disc brake by using thermal analysis and static structural analysis and coupled topological analogy iterations. For this analysis gray cast iron and stainless steel is used to compare results. Finally, in this research got result that if design requires high FOS better to go for Stainless steel, if not able to use gray cast iron for lighter weight product.**

Keywords: Finite element analysis, Static structural analysis, Thermal analysis, Topological analysis.

I. INTRODUCTION

Brake is an essential device in automotive parts. In order to have efficient control on system we will require quick and efficient brake system. In modern vehicle it is observed that disc brakes are widely used in brake control mechanism. the main principle which is used any braking system is kinetic energy is converted in the form of heat energy or potential energy, now a day in electronic vehicle we are using regenerative braking system.

The brake must be strong enough to stop the vehicle within any critical condition. the disc brake is a wheel brake generally two pads are used either side of plate, because of that dry friction is generated between disc surface and pads which is leads to convert kinetic energy into heat energy. The brake system also follows the law of conservation of energy. The disc brake is one of the brakes which use to push the stationary pads to hold rotating disc and generate friction to stop the vehicle.

Types of braking system:

1. Hydraulic brakes
2. Electric brakes
3. Mechanical brakes

The mechanical brakes further can be divided in two types' radial brakes and axial brakes.

Radial brakes: In those brakes the pressure performing on the brake drum is in radially acting. The radial brake can be subdivided into outside brakes and internal brakes.

Axial brakes: In those brakes the force appearing on the brake drum is best within the axial course. e.g., Disc brakes, Cone brakes.

Heat transfer in disc brake: By the law of thermodynamics heat transfer will takes place whenever there is temperature difference. in a disc brakes system due to lot of friction between pads and disc surface the frictional energy is converted into heat energy. So, there is need to have fast heat transfer in brake plates. If the temperature is very high during applications of bakes the brake may fail due to critical temperature and deformation will takes place in disc that may cause accident. So, in order to tackle this problem, there is need to study the modes of heat transfer.

Modes of heat transfer

Conduction: Conduction generally takes place in solid, static liquid and gases also. But heat transfer is a boundary phenomenon. Conduction happens due to molecular moment and electron vibration in a solid. Energy transfer will take place due to lattice vibration of molecules. Fourier's law of heat conduction and it express that the heat flow per unit area is proportional to the normal temperature gradient, where the proportionality constant is the thermal conductivity:

$$q = -KA\, delT/delX$$

Where q is the heat flux perpendicular to a floor of place A, [W]; A is the surface vicinity via which the heat drift takes place, [m2]; k is the thermal conductivity, [W/(mK)]; T is the temperature, [K] or [°C]; and x is the perpendicular distance to the surface travelled by means of the heat flux.

Convection: In a convection heat transfer takes place due to motion of the fluid. Convection is a combined effect of conduction and advection. The equation that represents

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convection comes from the Newton's regulation of cooling and is of the form:

Q=h*A* delta T

Where h is the convective heat transfer coefficient [W/(m2K)]; T∞ is the temperature of the cold fluid; and Ts is the temperature of the surface of the body.

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. To do analysis Ansys workbench is an essential tool to solve problems and compared with real life problems.

II. METHODOLOGY

Design of discs

Two different materials are used in this research to find out best material for weight reduction. Cero is used to design the disc plates, and workbench is used for analysis. To do thermal and static structural analysis and with that topological analysis. Topology analysis gives the best possible optimal design for weight reduction which leads to lighter weight with same values also it saves material consumption and cost of product is also reduced which is very economical to call file in workbench we have save file in igs or stp format.

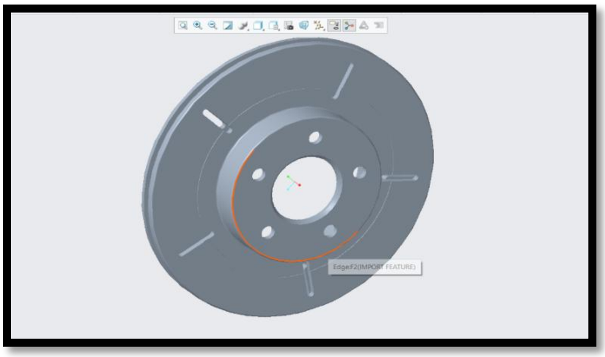

Figure 1: Basic design of disc brake

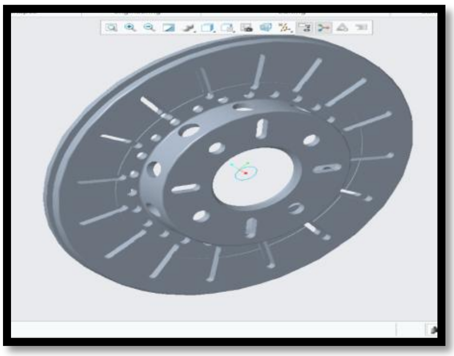

Figure 2: First optimized design of disc

Boundary conditions: In order to do analysis, there is need to have cleared cut idea about boundary condition in this research paper coupled analysis coupled analysis is performed to match real condition occurred during brake application.

III. BOUNDARY CONDITIONS FOR THERMAL ANALYSIS

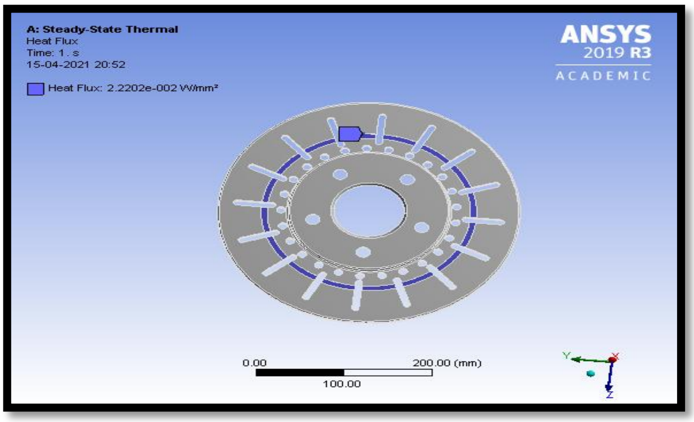

Figure 3: Heat flux boundary condition

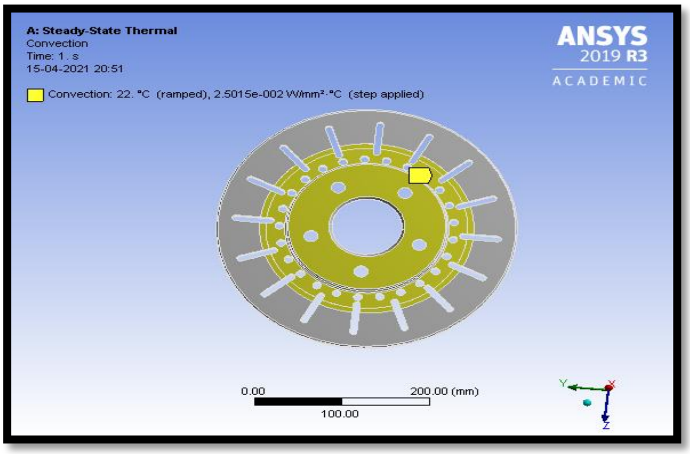

Figure 4: Convection boundary conditions

IV. BOUNDARY CONDITIONS FOR STATIC STRUCTURAL ANALYSIS

Table 1: Material properties

Material properties	Stainless steel	Cast iron
Thermal conductivity	36	50
density	7100	6600
Specific heat	320	380
Thermal expansion	0.12	0.16
Elastic modulus	210	110
Coefficient of friction	0.5	0.5
Film co-efficient	240	280
Angular velocity	2000	2000

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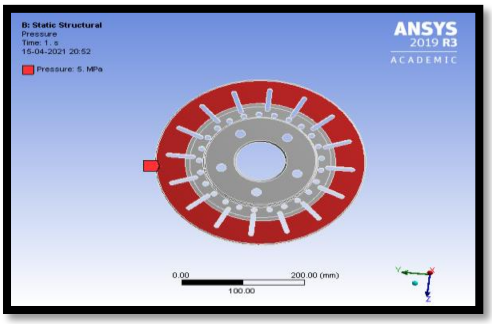

Figure 5: Static pressure boundary condition

V. THERMAL ANALYSIS

Thermal analysis is performed to find out maximum temperature generated in disc. So, we can protect disc from melting which will improve safety during brake application.

Disc no 1-Following result are obtained for disc 1 stainless steel

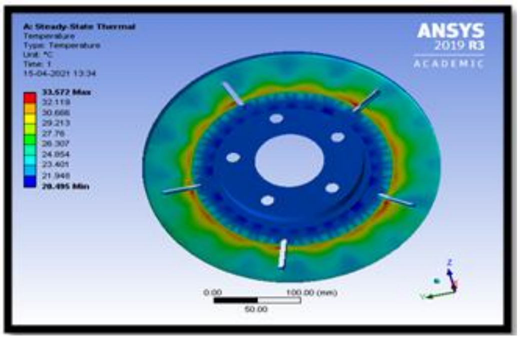

Figure 6: Temperature generation in disc no 1 of stainless steel material

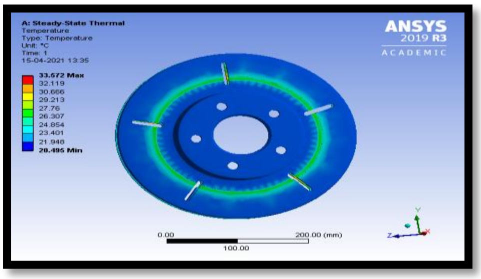

Figure 7: Temperature generation in disc no 1 of stainless steel material

Total heat flux for disc 1

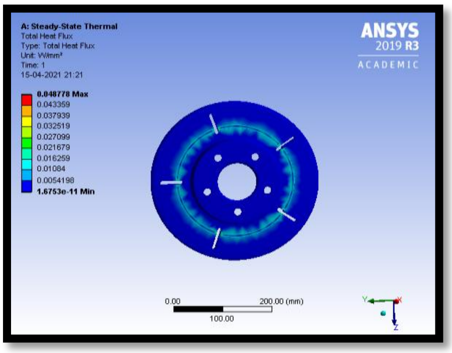

Figure 8: Total heat flux generated in Disc 1

Disc 1 thermal results of grey cast iron:

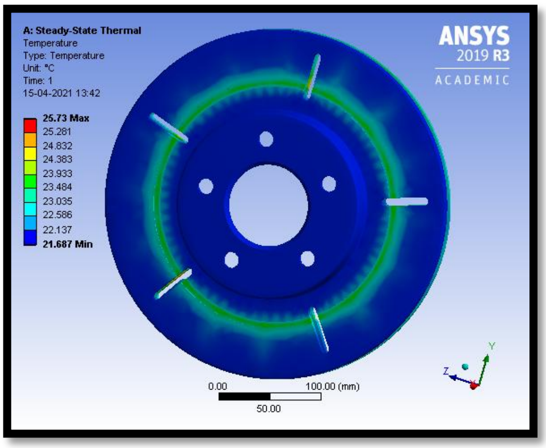

Figure 9: Temperature generation in disc 1 of gray cast iron material

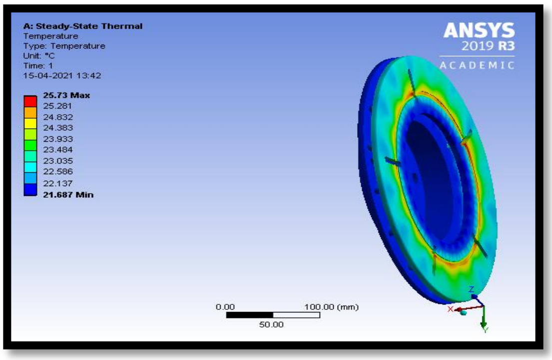

Figure 10: Temperature generation in disc 1 of gray cast iron material

Total heat flux:

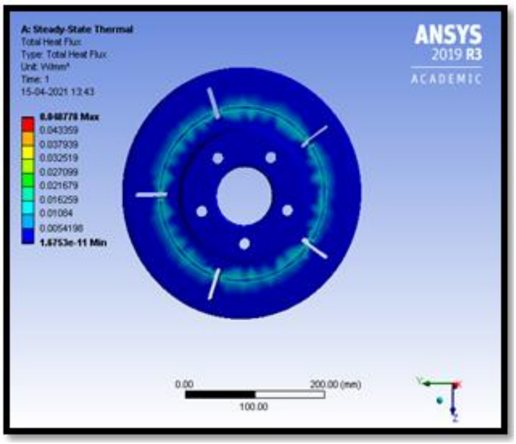

Figure 11: Total heat flux generated in Disc 1 of gray cast iron material

VI. STATIC STRUCTURAL ANALYSIS

Coupled static- Structural analysis is performed by applying pressure and rotational velocity in order to get perfect result.

Disc 1 for Stainless steel:

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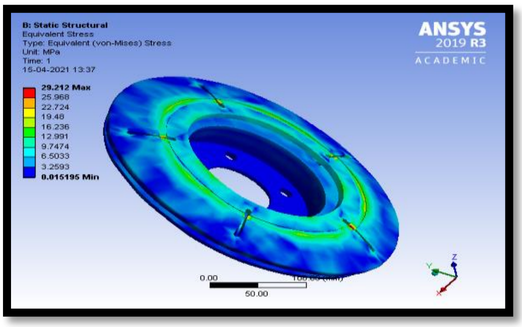

Figure 12: Stress generation in disc 1 of SS material

Disc 1 Grey cast iron:

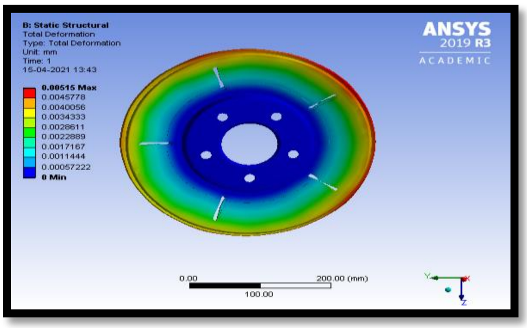

Figure 13: Total deformation Disc 1 of gray cast iron material

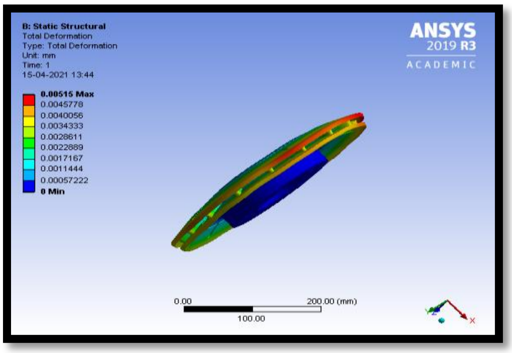

Figure 14: Total deformation of grey cast iron of Disc 1

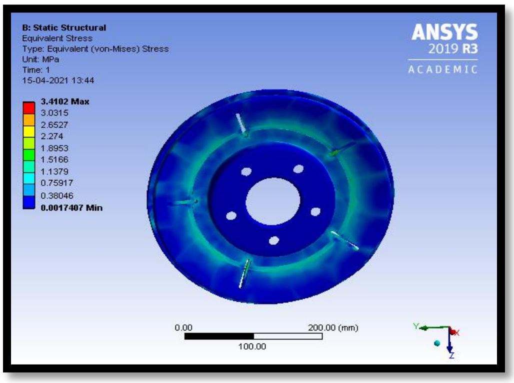

Figure 15: Stresses generated in Disc 1 of gray cast iron

VII. TOPOLOGICAL ANALYSIS

This analysis is performed after the static analysis by using this we can able to reduce mass of disc and able to optimize disc design it will give perfect indication to remove material from the part.

For disc 1 stainless steel material

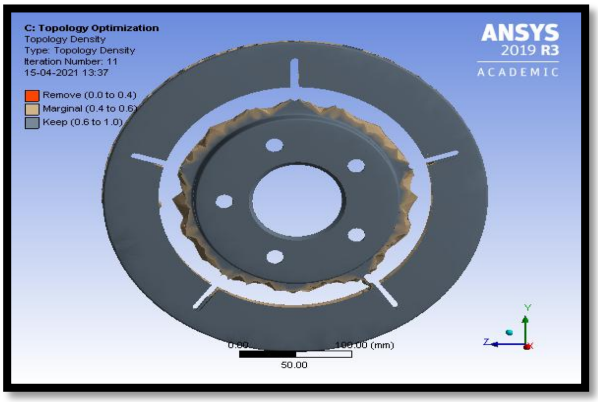

Figure 16: Topology result of Disc 1 of ss material

Disc 1 of gray cast iron:

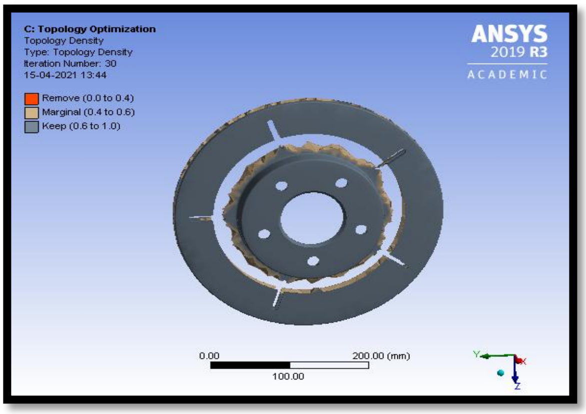

Figure 17: Topology optimization results of Disc no 1 made by gray cast iron

By analyzing above result updated design is generated in cero and again all procedure is repeated.

Disc no 2:

Thermal analysis results steel material:

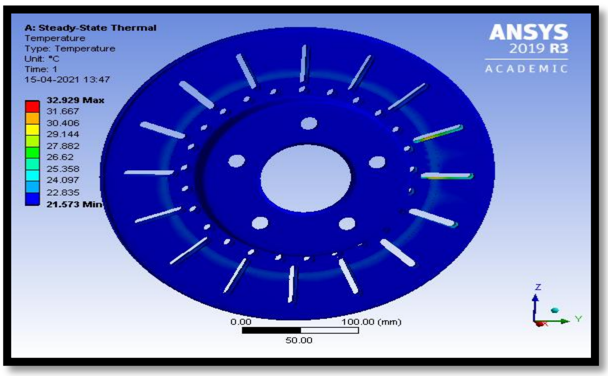

Figure 18: Temperature result of disc no 2 SS material

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https://doi.org/10.47001/IRJIET/2021.506015

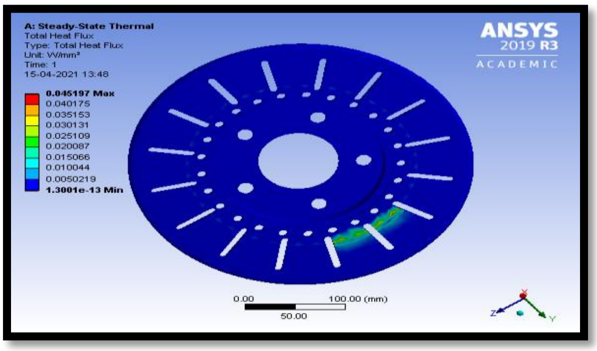

Figure 19: Heat flux result Disc 2 of SS model

Grey cast iron:

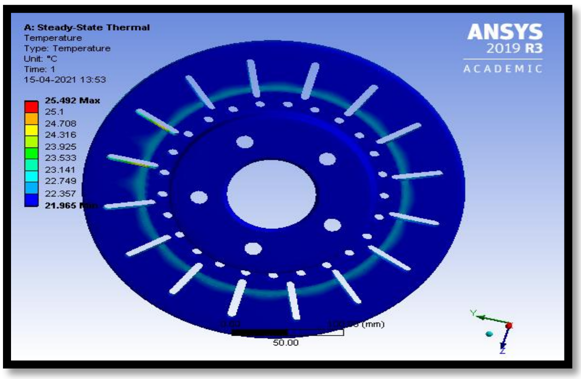

Figure 20: Temperature results of disc no gray cast iron material

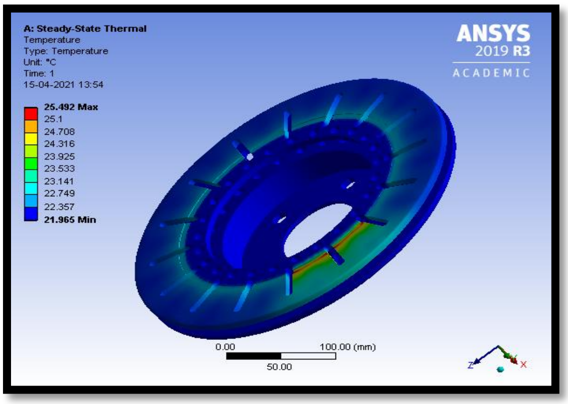

Figure 21: Temperature results of disc no gray cast iron material

Heat flux:

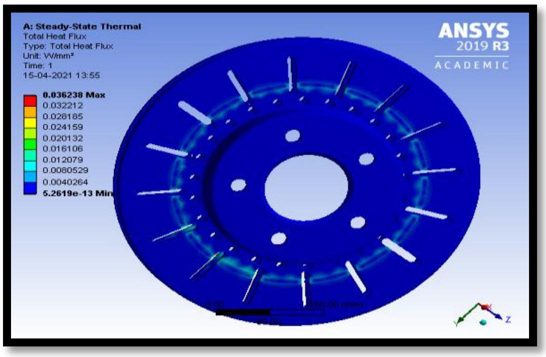

Figure 22: Heat flux result of gray cast iron of disc 2

Statics Steel Result:

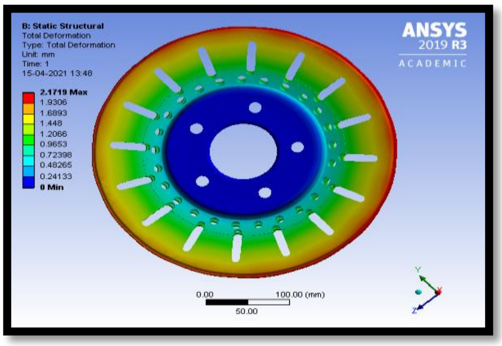

Figure 23: Deformation result of SS material disc 2

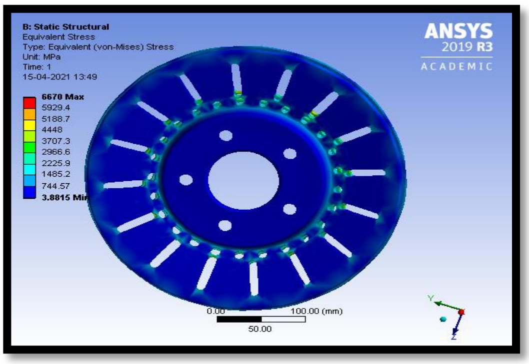

Figure 24: Equivalent stresses of SS material of D2

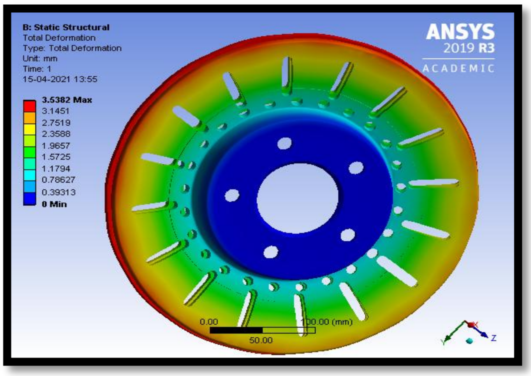

Figure 25: Total deformation of gray cast iron of D2

Stress:

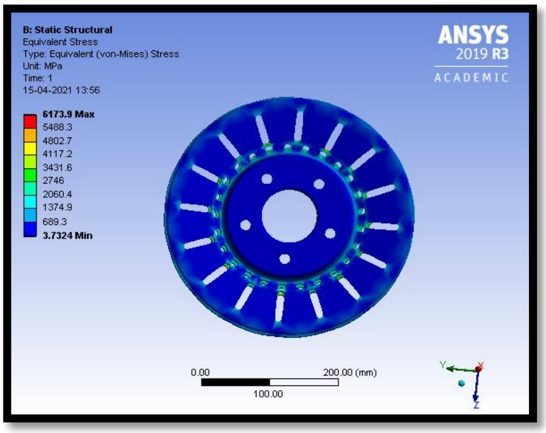

Figure 26: Equivalent stresses in gray cast iron material D2

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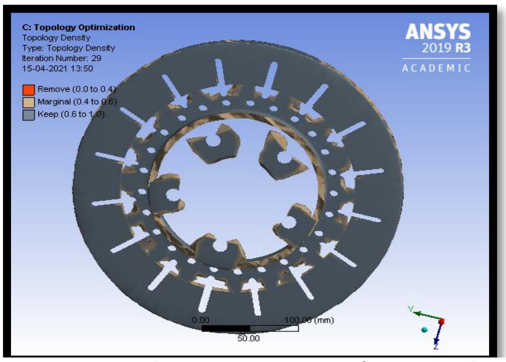

Figure 27: Topology optimization D2 of SS material

Gray cast iron Result:

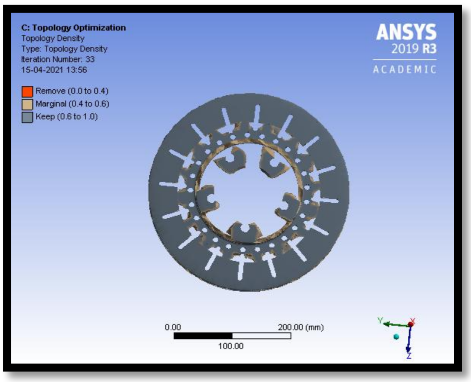

Figure 28: Topology optimization of gray cast iron of D2

Final design of disc brake:

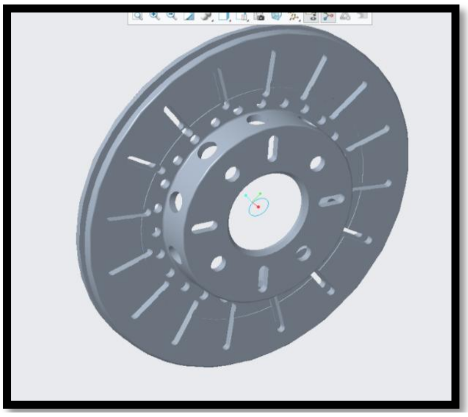

Figure 29: Final design of disc

VIII. RESULT TABLE

Table 2: Results

No	Material	Min temp (deg Celsius)	Max temp (deg Celsius)
Disc 1	Stainless steel	20.495	33.572
Disc 1	Grey cast iron	21.687	25.783
Disc 2	Stainless steel	22.573	35.929
Disc 2	Grey cast iron	21.965	25.482

Table 2: Results

Total heat flux	Max deformation (mm)	Max Deformation (mm)
0.0487	0	0.02179
0.0487	0	0.0051
0.045	0	2.1719
0.0362	0	3.5282

Table 4: Results

Stress (MPa)	Mass (Kg)
29.212	9.3004
3.4102	8.6404
6670	8.6587
6173	8.0442

IX. FINAL MASS

Table 5: Final Mass

No	Material	Mass (kg)
Disc 1	Gray cast iron	7.832
Disc 2	Stainless steel	8.431

X. DISCUSSION AND CONCLUSION

1. By performing FEA analysis it is found that we can able to optimize disc design.
2. In this research it is found that gray cast iron material will have low weight and low temperature generation as compared to stainless steel.
3. It is better to use gray cast iron rather than stainless steel.
4. If disc want high FOS better to use stainless steel.
5. Also by performing topological analysis able to find out areas from where material should be removed.

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AUTHORS BIOGRAPHY

Akash Waghmare,
College: Vishwakarma Institute of Information and Technology,
Branch: Mechanical Engineering,
Year: Third Year
Mail id: akash.21810324@viit.ac.in

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Aniket Salvi,
College: Vishwakarma Institute of Information and Technology,
Branch: Mechanical Engineering,
Year: Third Year
Mail id: aniket.21810407@viit.ac.in

Revati Mathpati,
College: Vishwakarma Institute of Information and Technology,
Branch: Mechanical Engineering,
Year: Third Year
Mail id: revati.21810389@viit.ac.in

Citation of this Article:

Akash Waghmare, Aniket Salvi, Revati Mathpati, "Design Optimization of Disc Brake Using Topology Analysis" Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 5, Issue 6, pp 75-81, June 2021. Article DOI https://doi.org/10.47001/IRJIET/2021.506015

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