Design and Analysis of Ventilated Disc Brake by using Different Materials and Geometry

Vivek Kumar Tripathi[1]
Research Scholar
[1]Department of Mechanical Engineering, JEC, Jabalpur,
Madhya Pradesh, India

Ruchika Saini[2]
Assistant Professor
[2]Department of Mechanical Engineering, JEC, Jabalpur,
Madhya Pradesh, India

U.K. Joshi[3]
Associate Professor
[3]Department of Mechanical Engineering, JEC, Jabalpur,
Madhya Pradesh, India

Abstract:- The component known as a disc rotor is utilize in automotive vehicle wheels to apply brakes. Frictional resistance between the pad and the rotor is what causes the brakes to work. The heat that is produced between the disc and pad as a result of frictional resistance must be reduced, hence the rotor is made of a vented disc. Grey Cast Iron is the most typical material utilize to make disc rotors. In this study, the structural analysis of the disc brake rotor was carried out using a variety of materials, including grey cast iron, titanium, magnesium alloy, aluminium alloy, and structural steel. Additionally, the study looked at various disc brake rotor geometries, and a final conclusive combination was recommended. The analysis was completed using ANSYS WORKBENCH 18.0 for structural analysis and CATIA for modelling. The optimum material and design that may be used to manufacture brake disc rotors have been determined via comparisons using various factors, such as deformation and equivalent stress.

Keywords:- *Disc Rotor, Titanium, Grey Cast Iron, Ventilated, Titanium, Topology Optimization.*

I. INTRODUCTION

The most crucial safety components in cars are the brakes. The purpose of brakes is to reduce the speed and stop wheel rotation. Braking pads are mechanically pressed against the rotor or disc on both surfaces to stop the wheel. For the safe operation of all vehicles, they are necessary. In a nutshell, brakes reduce a car's speed by converting the kinetic energy of the vehicle into thermal energy [1]. The primary concept of braking is to take the body's kinetic energy and transform it into frictional energy, which produces heat, which is then dispersed into the environment. [2] The loss of stopping power that can occur after applying the brakes repeatedly or continuously, particularly under situations of high load or high speed, is known as brake fade.[3] To determine the temperature distribution in discs, it is necessary to solve the appropriate heat transfer equations. The solution of this problem depends on the physical conditions existing at the boundaries of the medium and on the conditions existing in the medium. Huajiang Ouyang,Abd Rahim Abu-Bakar and Lijie Li [4] noted that the heat transferred due to friction is

$$q = \mu p v$$

Where μ is the friction coefficient, v is the sliding velocity of the disk at the point of contact and p is the contact pressure at the interface, q is the amount of heat generated by friction.

To stop the vehicle, friction material in the form of brake pads is forced mechanically, hydraulically, Pneumatically or electromagnetically against both sides of the disc [5] The disc brake and associated wheel slow down or stop due to friction. It is considered that heat is exchanged with the environment for the exposed area of the disc and brake pads through convection in addition to radiation. As a result, the boundary conditions for convection surface and radiation surface are applied as:

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$$q1 = h \times A \times (To - Ts) \text{ and } q2 = \varepsilon \times \sigma \times A \times [(T0)^4 - (Ts)^4]$$

When h is the average heat transfer coefficient, q1 and q2 represent the heat removed from the rotor by convection and radiation, respectively.

- *The Rotor's Area in Touch with the Environment is A.*

To is the disc brake rotor's surface temperature, Ts is the surrounding air's temperature, is the rotor's emissivity, and is the Stefan-Boltzmann constant.[5]

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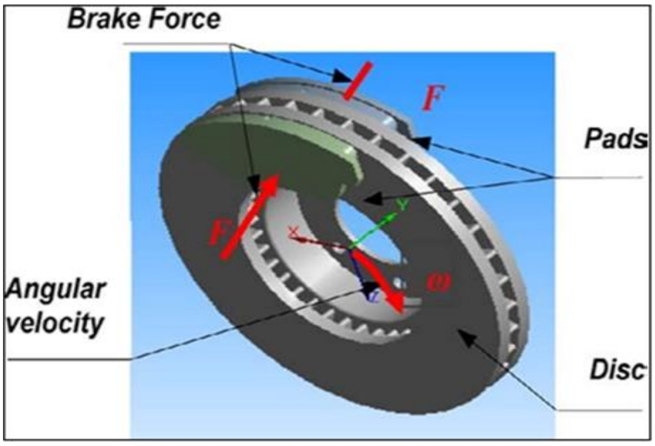


Fig 1 Schematic Diagram of Disc Brake

➤ *Disc Brake Components*

- *Caliper: The brake calipers have a two brake pads and wheel cylinder.*
- *Brake pad: The pad is mostly made on the nonmetallic materials eg. Ceramic materials.*
- *Piston: It is used to push the brake pad by the flow of brake fluid.*
- *Rotor or disc: It provides a smooth surface against which to face the brake pads, to slow or stop the vehicle.*
- *Master cylinder: Its carries the brake fluid we apply the brake to supply to wheel cylinder.*

II. MATERIAL SELECTION

➤ *General Material Requirements*

In disc brake systems, brake pads are clamped onto a rotor that is affixed to the hub to produce braking force. Due to the hydraulic and mechanical disc brakes' strong mechanical advantage, a little input lever force at the handlebar can be transformed into a significant clamp force at the wheel. Braking power is produced by the large clamp force that squeezes the rotor with friction material pads. More brake power will be produced if the pad's coefficient of friction is higher. Depending on the type of material used to make the brake rotor, the coefficient of friction may change [1] Service brakes often pay attention to the coefficient of friction measured while the car is driving.

In order to create rolling resistance and slow the automobile down, all contemporary disc brake systems rely on brake pads rubbing on the braking rotor on both sides. The frictional force is calculated by dividing the force pressing the pad against the rotor by the pad's coefficient of friction. Consequently, the force slowing the brake rotor or disc is F*R*ROTOR*R*=2C *R*f, pad *RF pad*.

Ground-based transportation systems' braking systems are essential safety features, so the structural materials used in brakes should have a variety of qualities, including good compressive strength, a higher friction coefficient, wear resistance, light weight, good thermal capacity, and economic variableness [1].

➤ *Properties of Material*

Table 1 below lists the characteristics of the various materials that were used for the analysis. Since some fundamental characteristics of materials, such as density, young's modulus, and poisson's ratio, must be known in order to define any material. This paper's study materials include grey cast iron, titanium, titanium alloy, aluminium alloy, magnesium alloy, and structural steel.

Table 1 Properties of all materials

Material	Density (kg/m^3)	Young's Modulus (MPa)	Tensile Strength (MPa)	Compressive strength (MPa)	Poisson's ratio
Grey Cast Iron	7200	$1.25*10^5$	240	240	.25
Structural steel	7850	$2*10^5$	250	250	.3
Titanium alloy	4620	$9.6*10^4$	930	930	.36
Copper alloy	8300	$1.1*10^5$	280	280	.34
Magnesium alloy	1800	$4.5*10^4$	193	193	.35
Aluminum alloy	2770	$7.1*10^4$	280	280	.33

III. SPECIFICATION OF DISC

➤ *Below Table 2 is Showing the Specification of Disc Rotor, this Table is Showing the General Dimensions of Disc Rotor.*

Table 2 Properties of all Materials

Sr. No.	Description	Unit	Value
1	Outer diameter of Disc brake rotor	mm	280
2	Inner diameter of Disc brake rotor	mm	225
3	Hub diameter	mm	130
4	Thickness of rotor	mm	5

IV. BOUNDARY CONDITIONS

Figure 2 and the table below illustrate the boundary conditions that were applied to the disc rotor using the ANSYS WORKBENCH 18.0 STATIC STRUCTURAL module.

Table 3 Boundary Conditions Applied on Disc Rotor

Sr. No.	Static Structural
1	Fixed Support
2	Pressure (1 MPa)
3	Rotational Velocity (157.89 rad/s)

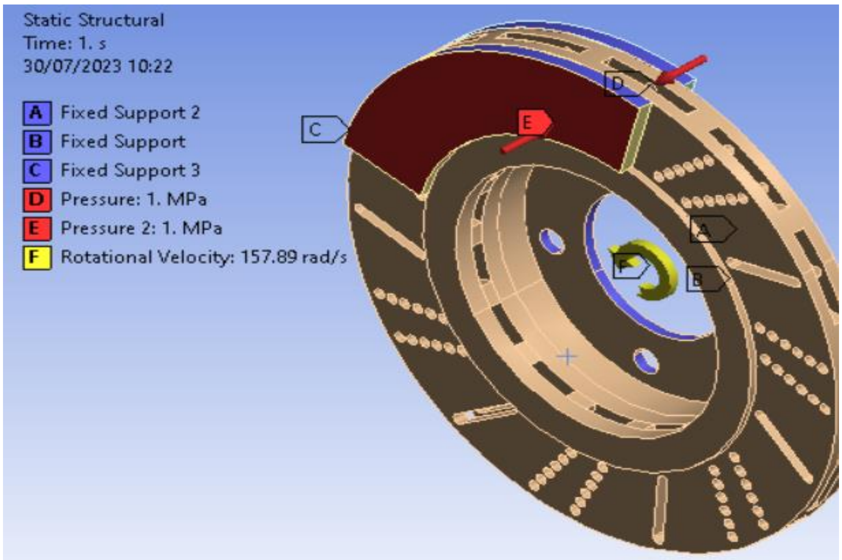


Fig 2 Boundary Conditions Applied on Disc Rotor

V. COMPARISON AND ANALYSIS

The disc's structural analysis is carried out using ANSYS WORKBENCH 18.0. The findings of the analysis are given in the photos below; only the results for the titanium alloy (TI550) and grey cast iron are shown, and the results for all materials are described in the following section using graphs and tables.

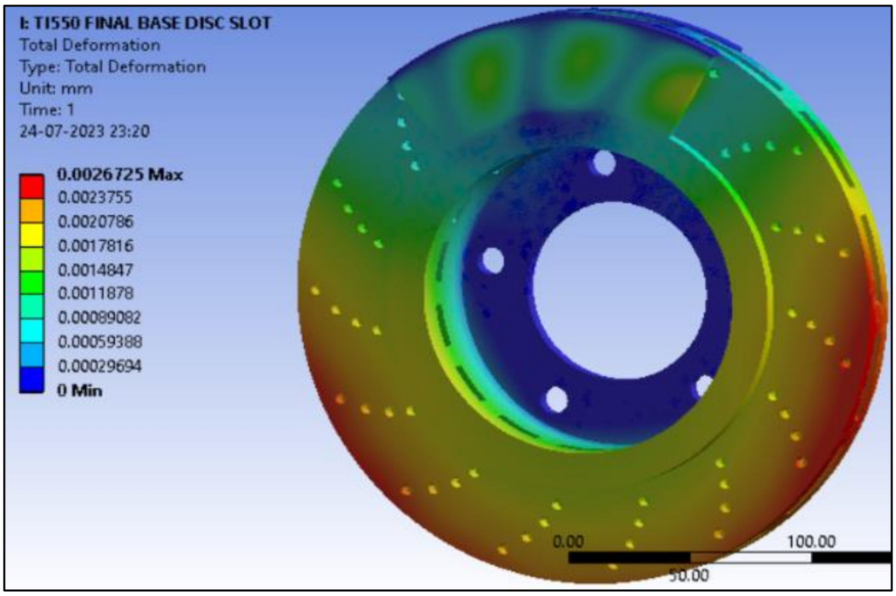


Fig 3 Deformation on Titanium Alloy (TI550)

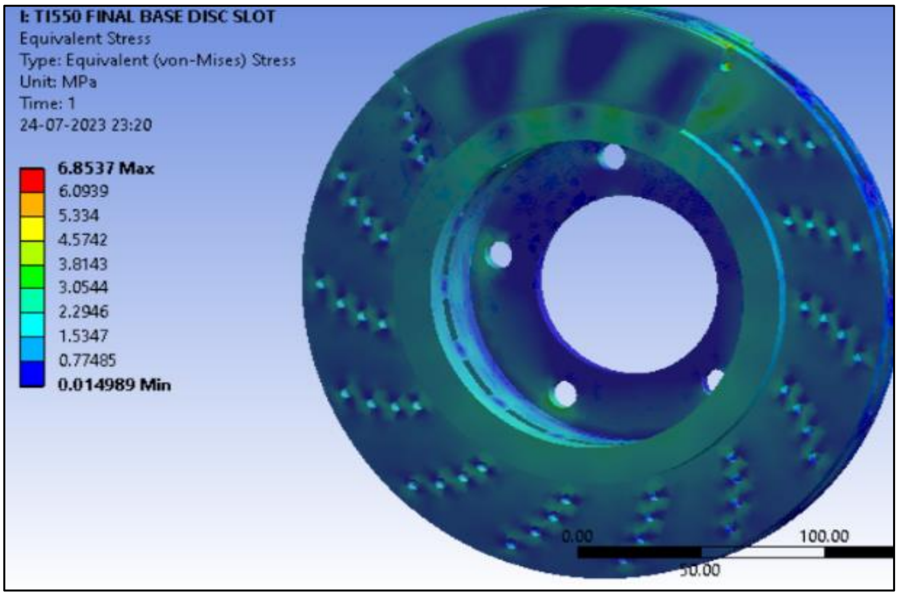


Fig 4 Equivalent Stress on Titanium Alloy (TI550)

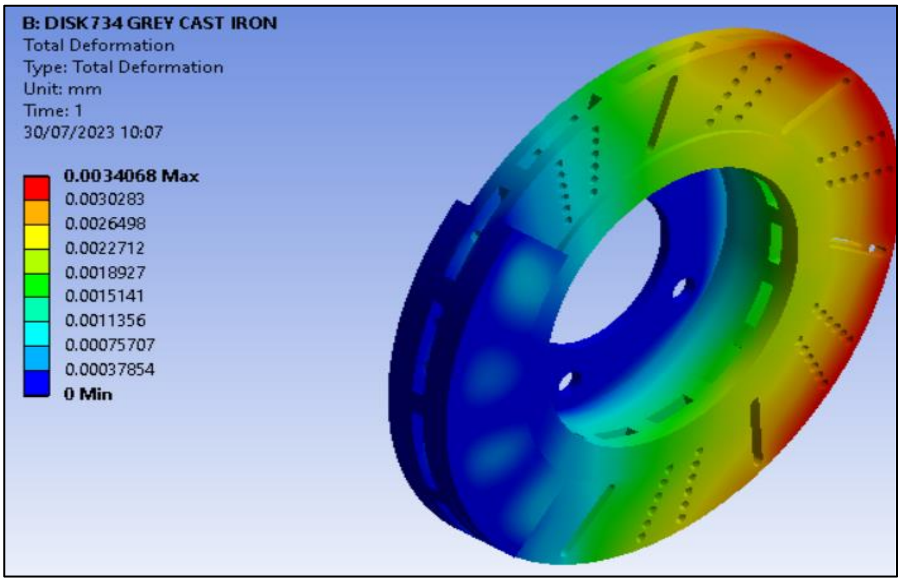


Fig 5 Deformation on Grey Cast Iron

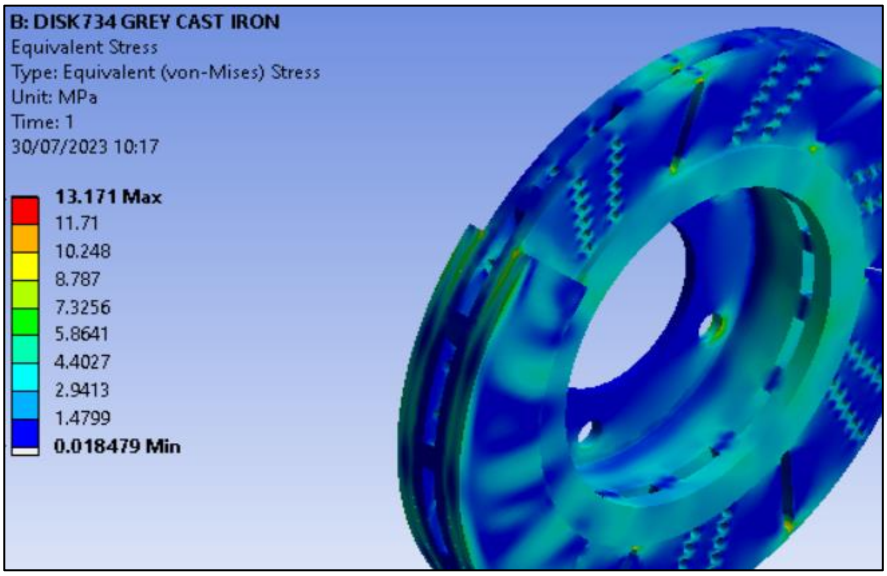


Fig 6 Equivalent Stress on Grey Cast Iron

- *Some More Images which show the Deformation and Equivalent- Stresses of Disc Rotor Braker with Different Geometries. Are :*

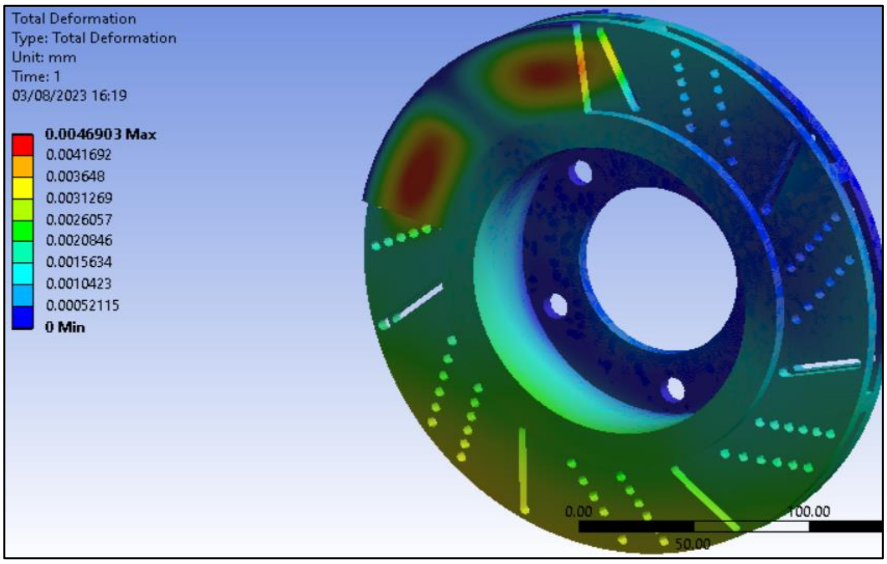


Fig 7 Deformation on Disc Brake with Elongated Hole

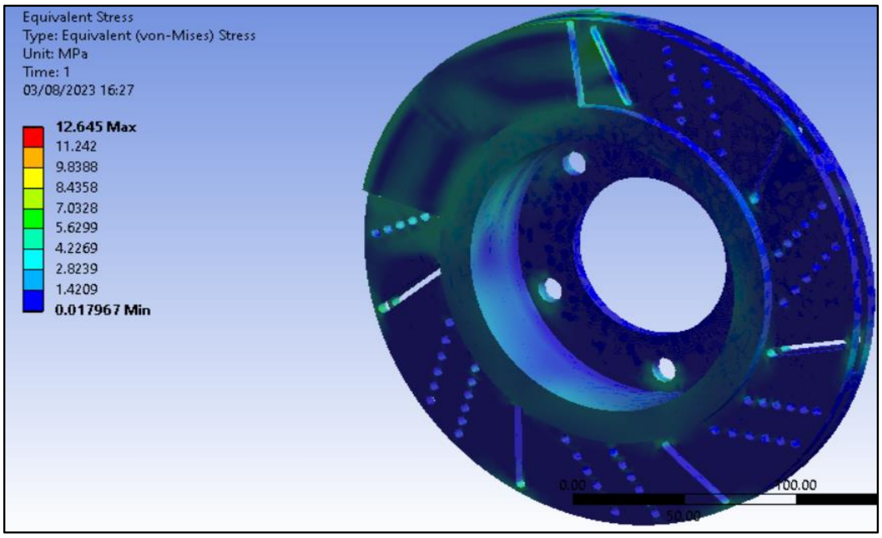


Fig 8 Equivalent Stress on Disc Brake with Elongated Hole

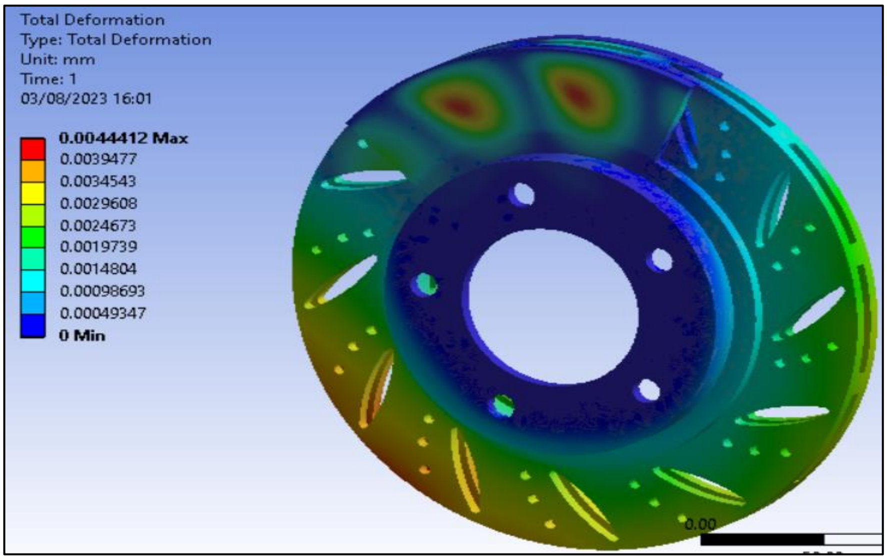


Fig 9 Deformation on Disc Brake with Elliptical Hole

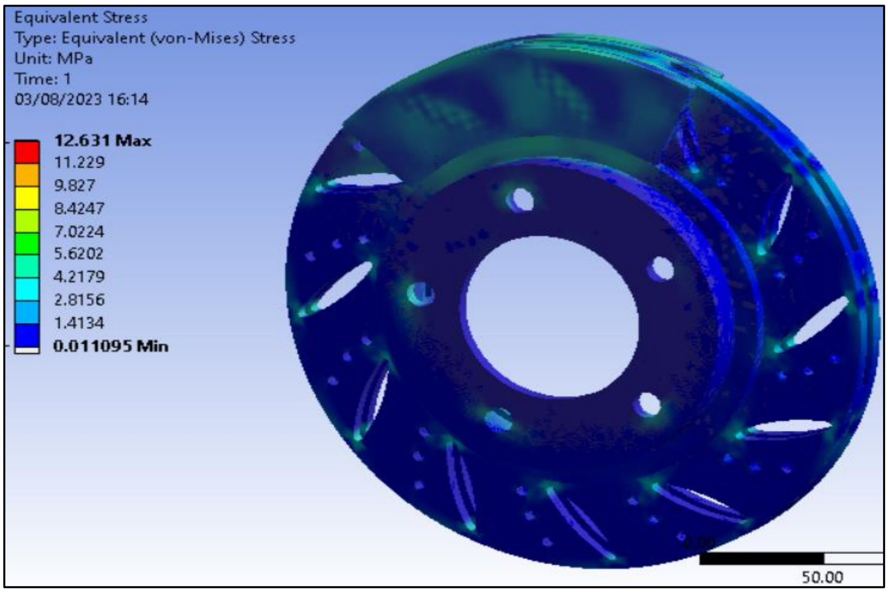


Fig 10 Equivalent Stress on Disc Brake with Elliptical Hole

VI. RESULTS GRAPHS AND TABLES

➢ *Results Graphs and Tables (Using Different Materials)*

Deformation and equivalent stress in disc brake rotors have been demonstrated using various materials in this section through Figure variation 11.a and 11.b and table 4 From the graph and table, it is evident that, when results are contrasted with those obtained using the conventional material (Grey Cast Iron), all other materials exhibit superior performance. Additionally, it can be seen that magnesium and aluminium alloy exhibit superior performance, and from Figure variation 11.c, it can also be seen that the weight of the disc brake rotor is less.

Table 4 Deformation and Equivalent Stress on disc of Different Materials

MATERIALS USED	DEFORMATION (mm)	EQUIVALENT STRESS (MPa)
Ti550	0.0023887	3.7998
Copper Alloy	0.0041071	6.5922
Aluminium Allloy	0.0021258	2.2326
Gray Cast Iron	0.010136	11.776
Megnasium Alloy	0.0021782	1.4136
Structral Steel	0.0021374	6.5592

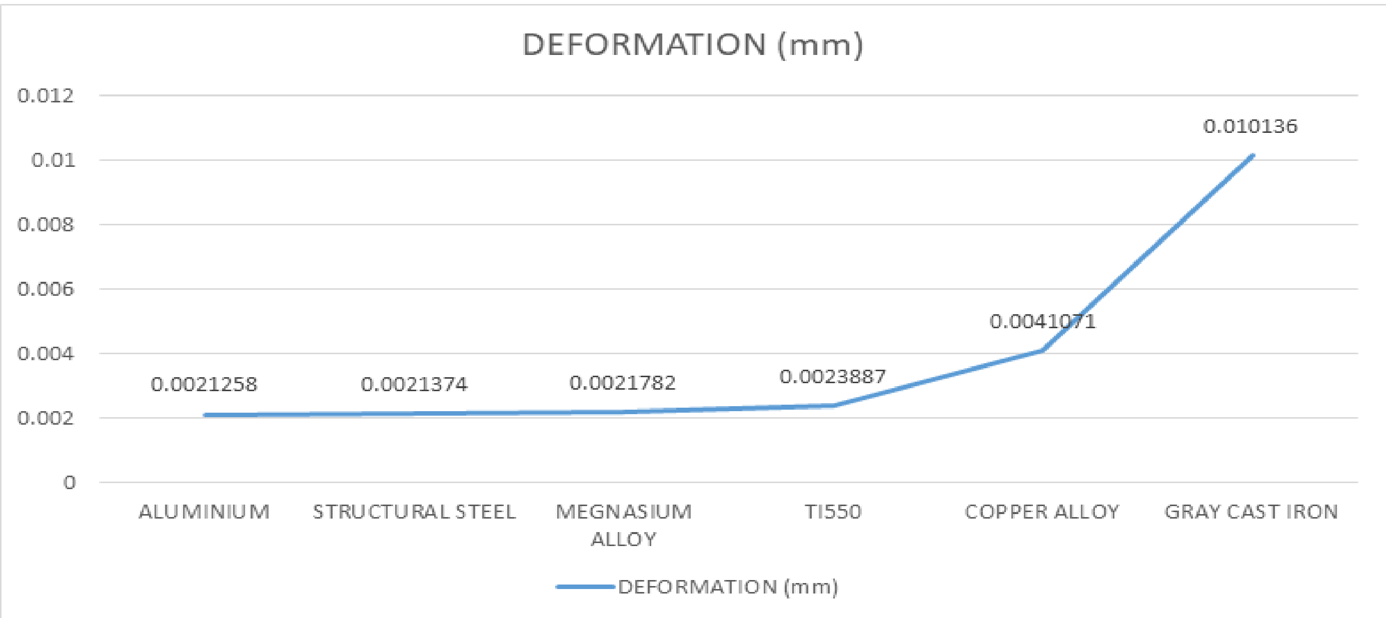


Fig 11a The Variation of the Total Deformation for all different Materials

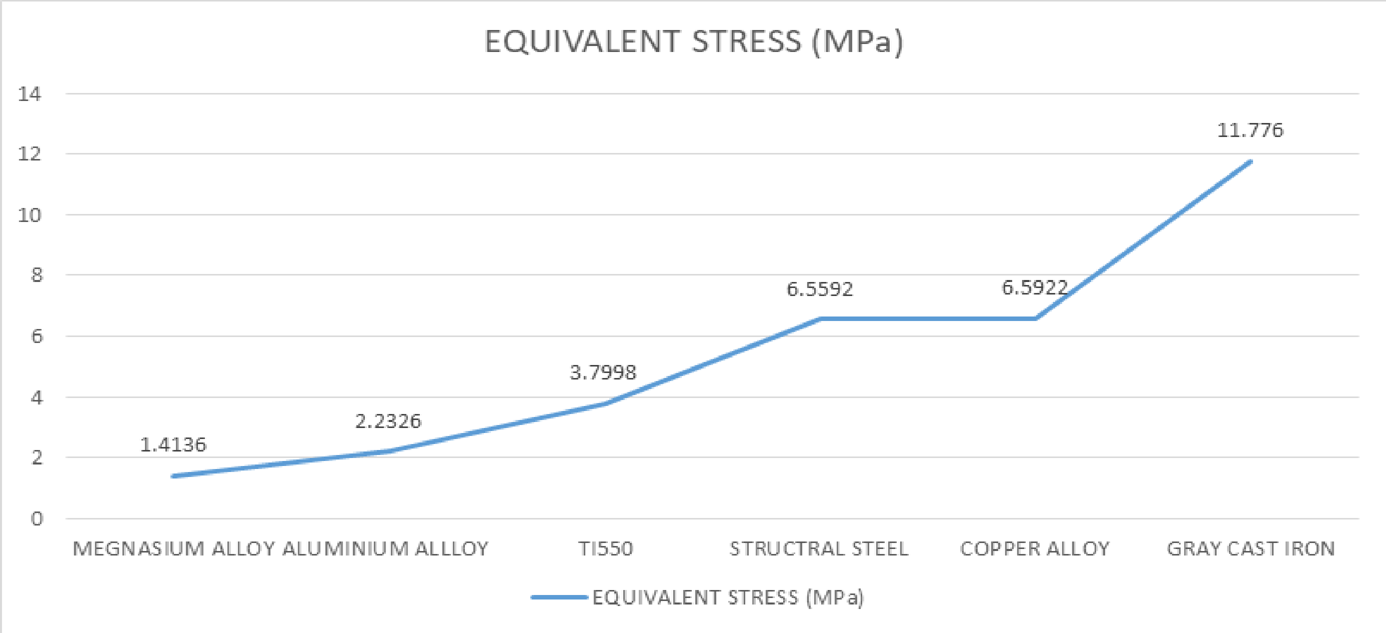


Fig 11b The Variation of the Equivalent Stress for all different Materials

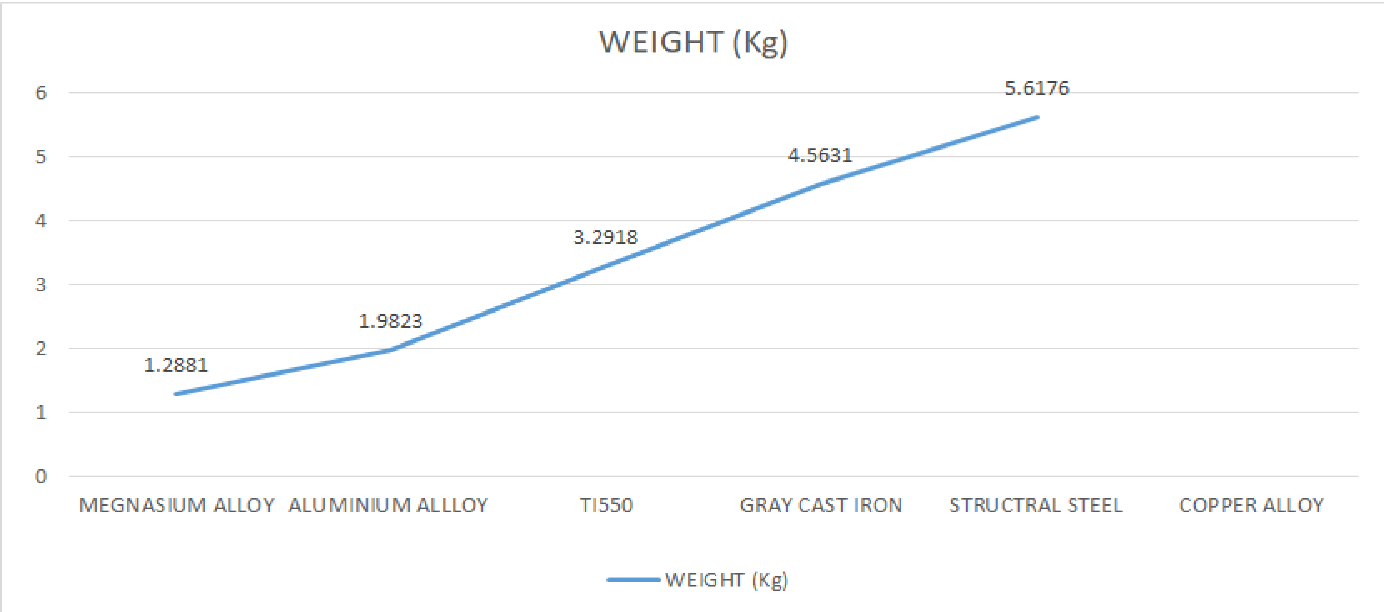


Fig 11c The Variation of The Weight of Disc Brake Rotor with Different Materials (kg)

- *Results Graphs and Tables (Using Different Design)*

Below, deformation and equivalent stresses in disc brake rotors have been demonstrated using various designs and taking Titanium, the material used in our foundational research. It is evident from figures 12.a and 12.b as well as table 5 that a disc with a thickness of (-1 mm) produces the greatest results when all factors, including deformation, equivalent stress, and disc weight, are taken into account.

Table 5 Deformation and Equivalent Stress on Disc of Different Design

DISC BRAKE ROTOR DESCRIPTION	DEFORMATION (mm)	EQUIVALENT STRESS (MPa)
Reference Disc Brake	0.0023887	3.7998
Disc Brake (-1mm Thickness)	0.0025851	7.0839
Disc Brake (-0.5 Mm Thickness)	0.0028701	7.0838
Disc Brake With Radial Slot	0.0026725	6.8537
Disc Brake With Elongated Slot	0.0046903	12.645
Disc Brake With Elliptical Slot	0.0044412	12.6301
Disc Brake With Holes (5 Nos)	0.0025519	6.5757

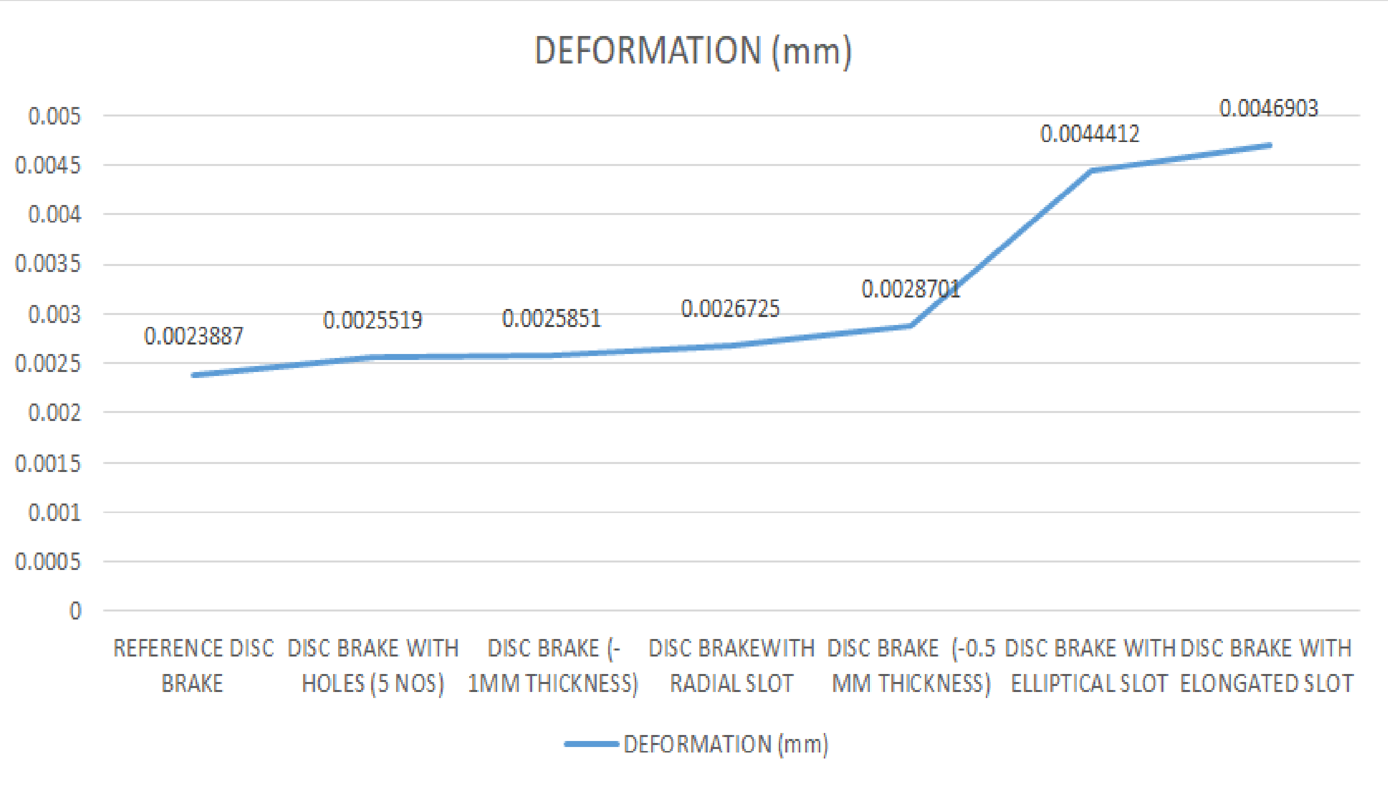


Fig 12a The Variation of the Total Deformation for all different Design.

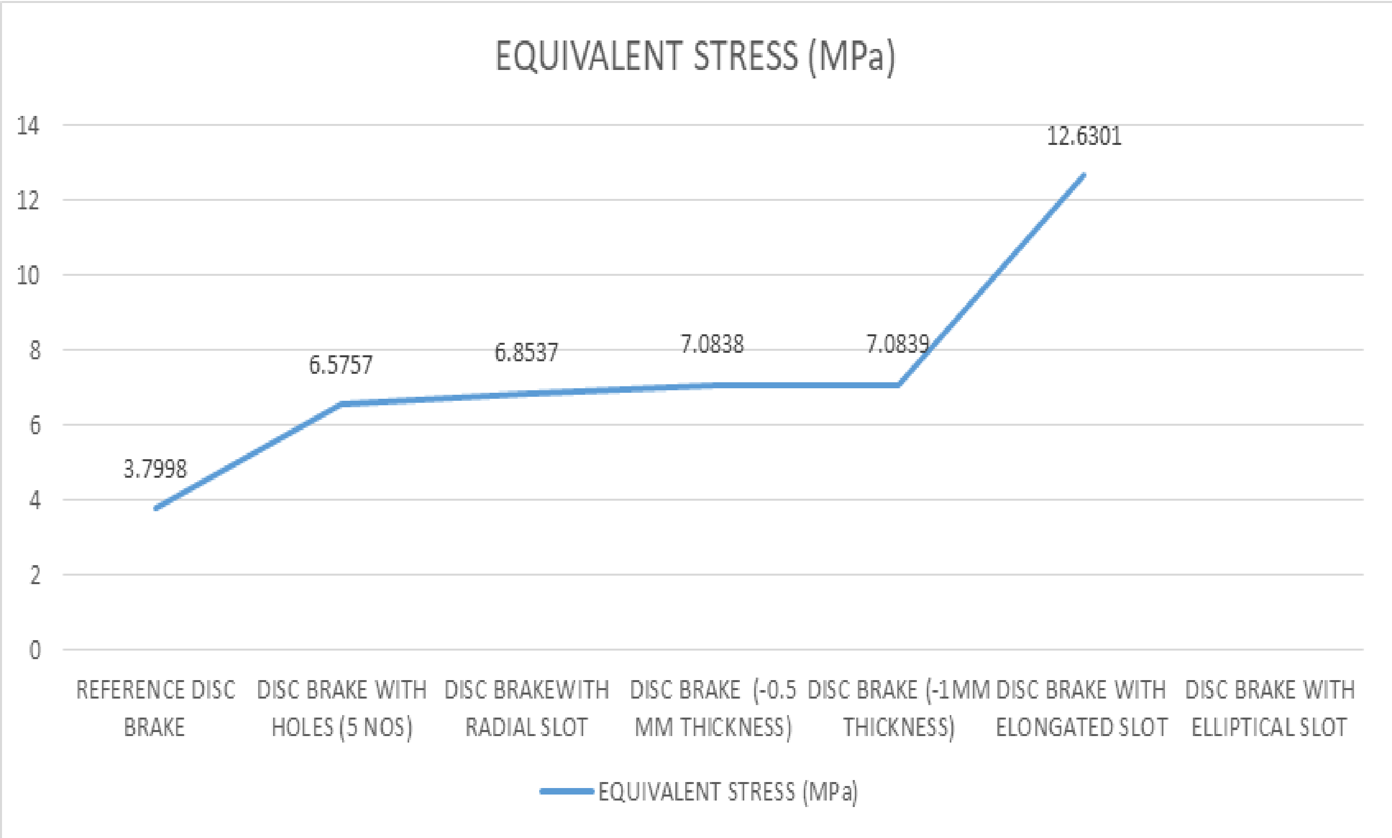


Fig 12.b The Variation of the Equivalent Stress for all different Design.

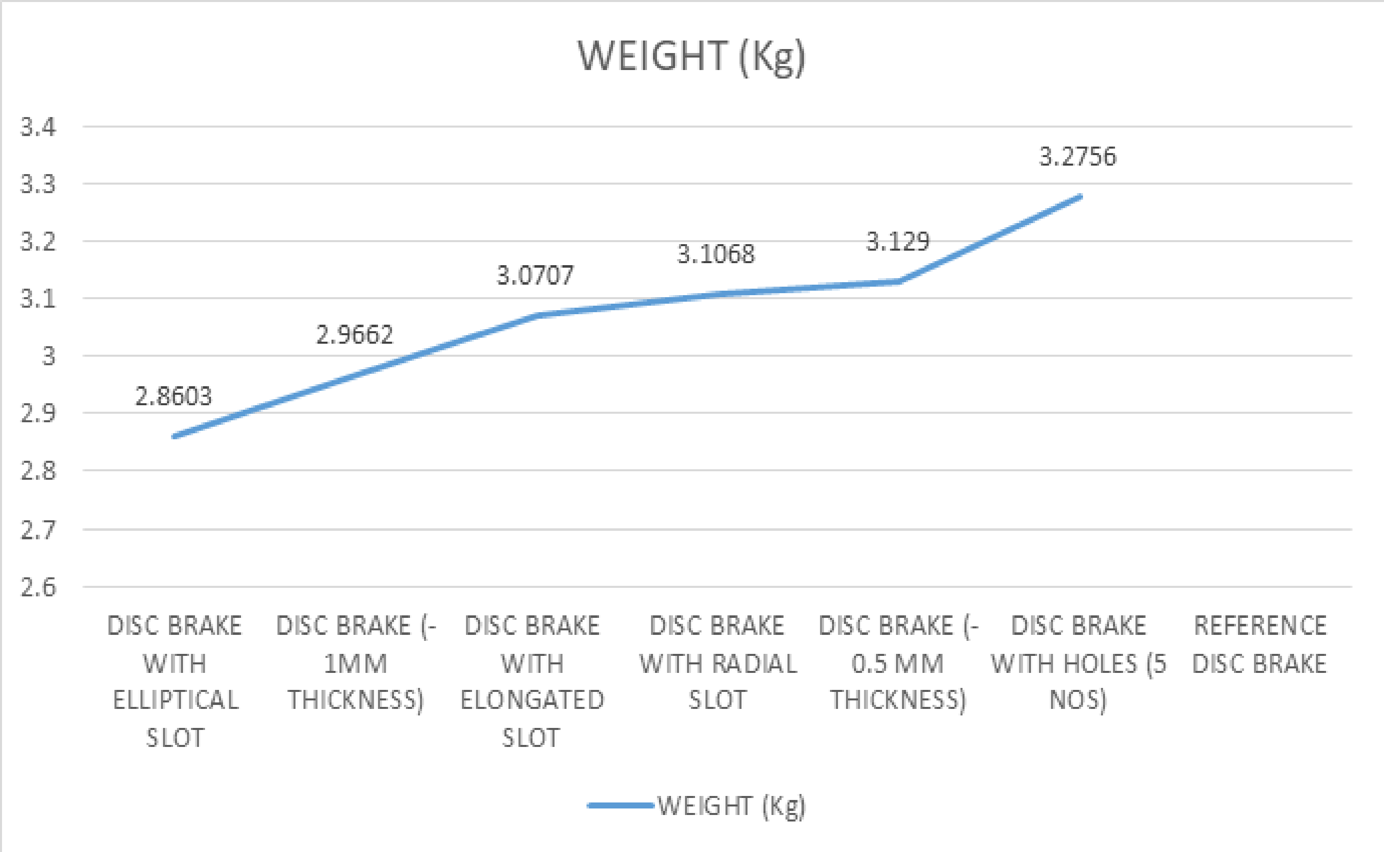
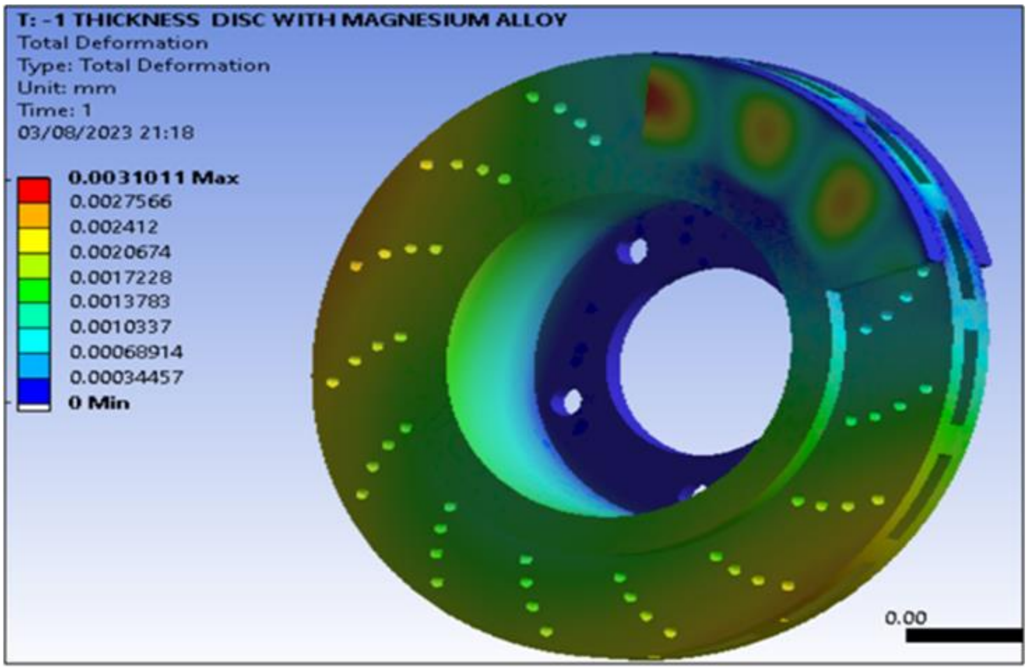


Fig 12.c Weight of disc brake rotor of different designs

VII. RESULTS

- After analysis of the disc brake in above two conditions, the final model has been taken from the best condition occur by considering results of different materials and different designs.
- The combined condition which has been taken is (-1mm thickness brake disc with magnesium alloy as material) from the fig 13 below the maximum deformation of .0031 mm is coming .
- Maximum equivalent stress of 5.2755 MPa is coming which is in very safe limit, another benefit of taking this design is that the weight of disc is also reduced to 1.1607 Kg only.



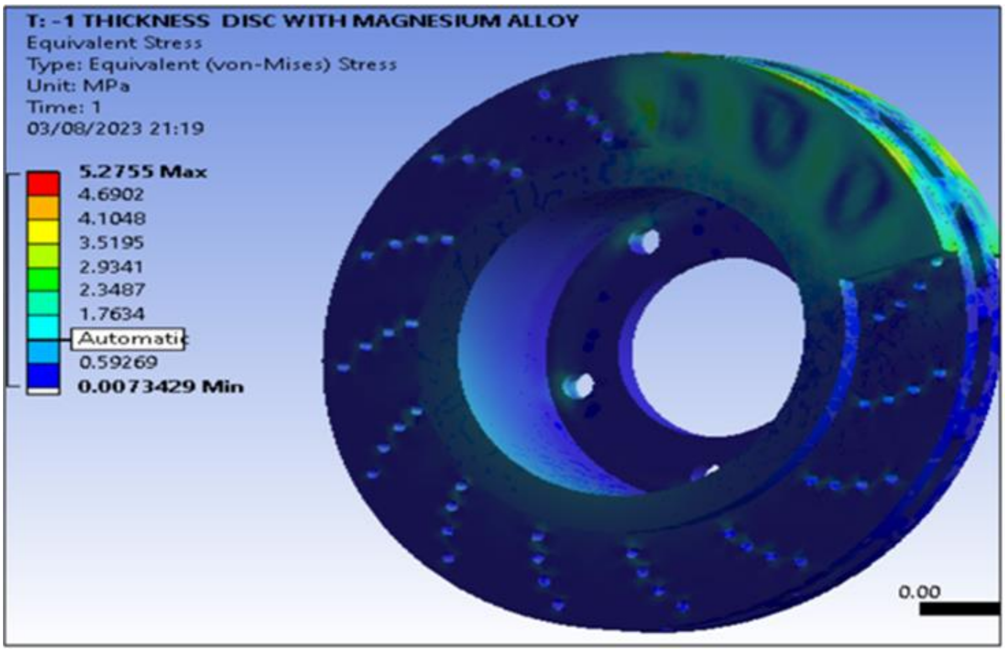


Fig 13 Total Deformation and Equivalent Stress in (-1mm thickness) Disc with Magnesium alloy Material.

VIII. CONCLUSIONS

- As discussed above the analysis on disc brake rotor has been done by using static structural analysis of ANSYS WORKBENCH 18.0. analysis has been done by taking 6 types of material which has been mentioned above and comparison has been done with conventional material used for disc brake rotor Grey Cast Iron.
- From above graphs and table it is clearly shown that all other materials have been performing better than Grey Cast Iron, and amongst all Magnesium alloy showing the best results. In second case of changing design of brake disc rotor the rotor with (-1 mm thickness is showing the best result. However these results have been concluded on the basis of static structural conditions only and not by considering thermal effect, so in future work same work can be done by considering thermal effect also.

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