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Structural and Thermal Analysis of Brake Disc Rotor using different Materials

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Abstract: ***Braking system is one of the important safety components of a vehicle. It is mainly used to decelerate vehicles from an initial speed to a given speed. A friction based braking system is a common device to convert kinetic energy into thermal energy through a friction between the brake pads and the rotor faces. Because high temperatures can lead to overheating of the brake fluid, seals and other components, the stopping capability of a brake increases with the rate at which heat is dissipated due to forced convection and thermal capacity of the system. The braking system was designed as a hydraulic system with two master cylinders, one for the braking of the front two tires and one for braking of the rear two tires. Attached to each master cylinder are two universal mount calipers, one located at each of the tires for a total of four calipers for the system, as well as four rotors or brake discs. The present research is basically deals with the modeling and analysis of solid and ventilated disc brake using Solidworks and Ansys. CAD models of the brake-disc are created using SolidWorks and simulated using ANSYS which is based on the finite element method (FEM). In this research Coupled Analysis (Structural & Thermal analysis) is performed in order to find the strength and heat dissipation of the disc brake. In structural analysis displacement, the ultimate stress limit for the design is found and in thermal analysis thermal gradients, heat flow rates, and heat fluxes to be calculated by varying the different cross sections, materials of the disc. Comparison can be done for displacement, stresses, nodal temperatures, etc. for the three materials to suggest the best material.***

Keywords: Disc Brake, Modeling, Ansys, Solidworks, Structural Analysis, Thermal Analysis.

I. INTRODUCTION

Braking system is one of the important safety components of a vehicle. It is mainly used to decelerate vehicles from an initial speed to a given speed. A friction based braking system is a common device to convert kinetic energy into thermal energy through a friction between the brake pads and the rotor faces. Because high temperatures can lead to overheating of the brake fluid, seals and other components, the stopping capability of a brake increases with the rate at which heat is dissipated due to forced convection and thermal capacity of the system. The braking system was designed as a hydraulic system with two master cylinders, one for the braking of the front two tires and one for braking of the rear two tires. Attached to each master cylinder are two universal mount calipers, one located at each of the tires for a total of four calipers for the system, as well as four rotors or brake discs.

A. Types of Brakes

1) *Drum Brake:* A drum brake is a traditional break in which the friction is caused by a set of shoes or pads that press against a rotating drum-shaped part called a brake drum. The term \"drum brake\" usually means a brake in which shoes press on the inner surface of the drum. Where the drum is pinched between two shoes, similar to a standard disk brake, it is sometimes called a \"pinch drum brake\", although such brakes are relatively rare.
2) *Disc Brake:* The disc brake is a mechanism for slowing or stopping the rotation of a wheel from its motion. A disc brake is normally made of cast iron, but in some cases, it is also made of composites such as carbon-carbon or ceramic -matrix composites. This is linked to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads is forced against both sides of the disc. Friction caused, on the disc wheel will slow or stop. The disc brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or rotor in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade. A fixed brake disc is a one-piece brake disc. That is, its brake pad contact face and wheel mounting face are all part of the same

piece of metal. They are relatively cheap to produce and they perform perfectly well within certain parameters, but if they are subjected to serious heat then they are unable to dilate or expand because they are not floating. Full Floating means that the outer rim of the rotor (the braking surface) is allowed to move slightly with respect to the solid center of the brake disc. Both fully floating brake discs and semi-floating brake discs are constructed in two parts. A mild steel center part which is fixed to the motorcycle wheel and a stainless rotor part which the brake pads push on

a) A floating rotor will find its own optimal path through the brake caliper. This means reduced brake drag (friction) which lets you put more horsepower to the ground instead of wasting it. They also help control disc warping under hard braking by allowing the braking surface to expand and contract naturally.
b) Second, they reduce the weight of your brake rotors. This reduces unsprung, rotating, mass. This has a similar benefit to lightweight wheels: better acceleration and faster turn-in.
c) Floating rotors tend to have less alignment problems with pads and pads wear is more uniform because of the float.

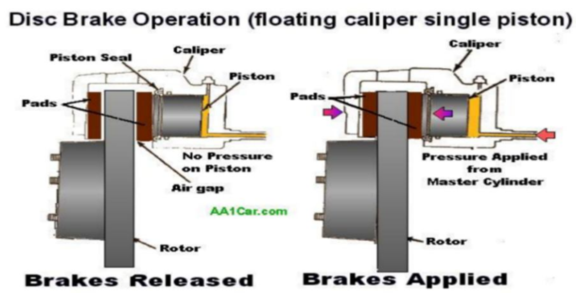

Fig 1. Floating Rotor

II. LITERATURE REVIEW

1) *M.A. Maleque, S. Dyuti and M.M. Rahman* studied the material selection methods for the design and application of automotive brake disc are developed. Functions properties of the brake discs or rotors were considered by using Ashby's materials selection chart. The digital logic method showed the highest performance index for AMC 2 material and identified as an optimum material among the candidate materials for brake disc. In the digital logic method, the friction coefficient and density were considered twice for determining the performance index and the cost of unit property. This procedure could have overemphasized their effects on the final selection.
2) *V. Chengal Reddy, M. Gunasekhar Reddy, Dr. G. Harinath Gowd* The present study can provide a useful design tool and improve the brake performance of disk brake system. From the above Table we can say that all the values obtained from the analysis are less than their allowable values. Hence the brake disk design is safe based on the strength and rigidity criteria. Comparing the different results obtained from analysis. It is concluded that ventilated type disk brake is the best possible for the present application. By observing analysis results, maraging steel is best material for Disc Brake.
3) *Ali Belhocine, Mostefa Bouchetara* presented a numerical simulation of the thermal behavior of a full and ventilated disc in transient state. By means the computer code ANSYS 11 was able to study the thermal behavior of three types of cast iron (AL FG 25, FG 20, FG 15) for a determined braking mode. In addition to the influence of the ventilation of the disc, we also studied the influence of the braking mode on the thermal behavior of the disc brake. The numerical simulation shows that radial ventilation plays a very significant role in cooling of the disc in the braking phase. The obtained results are very useful for the study of the thermomechanical behavior of the disc brake (stress, deformations, efficiency and wear). Through the numerical simulation, we could note that the quality of the results concerning the temperature field is influenced by several parameters such as:

a) Technological parameters illustrated by the design,
b) Numerical parameters represented by the number of element and the step of time.
c) Physical parameters expressed by the type of materials.
d) Braking mode implemented.

About the results obtained, in general, on can say that they are satisfactory in comparison with already carried out research tasks. It would be interesting to solve the problem by introducing depth the effect of thermomechanical coupling in reality. Compared to the prospects, one finds interesting to also make an experimental study of the disc of brake for example on test benches in order to show a good agreement between the model and reality.

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III. DESIGN OF BRAKE DISC ROTOR

A. Modeling of Disc Rotor

We design brake disc on solid works with the help of suitable solid works commands. With suitable diameter. Solid works is a designing software its good & easy software as compare from CATIA, & AUTOCAD. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SOLIDWORKS means that the dimensions and relations drive the geometry, not the other way around. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. SOLIDWORKS allows the user to specify that the hole is a feature on the top surface, and will then honor their design intent no matter what height they later assign to the can.

B. Drafting (Cad Model)

Drawings and documentation are the true products of design because they guide the manufacture of a mechanical device. SOLIDWORKS automatically generates associative drafting from 3D mechanical designers and assemblies. Associability of the drawings to the 3D master representation enables to work concurrently on designs and drawings. SOLIDWORKS enriches generative Drafting with both integrated 2D interactive functionality and a productive environment for drawing dress-up and annotation.

1) Conceptual Model, Cad model of Brake Disc Rotor is shown in Fig. 3.1.
2) Actual Draft, draft of actual model shown in Fig. 3.2.

Fig. 2. Rendered Image of Design

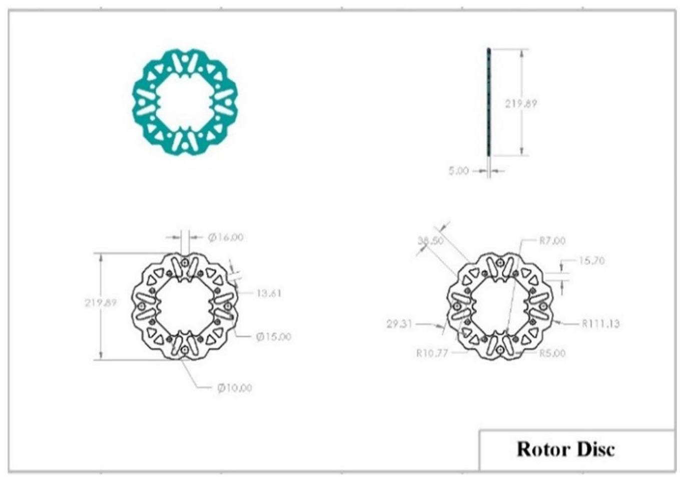

Fig. 3. Final Draft

C. Finite Element Method (FEM)

It is a numerical technique for finding the approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into the problem by minimizing an associated error function. The subdivision of the whole domain has several advantages:

1) Accurate representation of the complex geometry.
2) Inclusion of dissimilar material property.
3) Easy representation of the solution.
4) Capture of the local effects.

It divides the domain into a group of sub subdomain; every subdomain is represented by a set of element equations of the original domain.

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IV. MATERIALS USED FOR DISC BRAKE

A. Cast Iron

Metallic iron containing Carbon 2 to 5%, Silicon 1 to 3%, but may also contain a small percentage of Sulfur, Manganese and Prosperous within its matrix is referred to as gray cast iron because of its characteristic color. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution, and form of the precipitation of the excess carbon.

This is done to minimize distortion in machining, provide good wear characteristics, dampen vibration and resist cracking in subsequent use. The cast-iron disc is the heaviest of all types and also has a disadvantage information of rust. They usually range from 6-8 kgs for each disc of a car. But they are still preferred for high powering vehicles.

B. Aluminum Alloy

Aluminum alloys are used in advanced applications because of high strength, low density, durability, machine ability, availability, and cost are very attractive compared to competing materials. The aluminum metal matrix composite materials are the combination of two or more constituents in which one is matrix and other is filler materials (reinforcements). The Aluminum metal matrix may be laminated, fibers or particulate composites.

Generally, grey cast iron is used to manufacture brake disc rotor, but AMMC is selected considering crucial advantages of the AMMC over cast iron material. Disc brake used for decelerating or stopping the automobile or to maintain a constant velocity or to park the vehicle.

This specification dictates the correct range of hardness, chemical composition, tensile strength and other properties necessary for the intended use. Aluminum alloy discs are light, they were less resistant to heat and fade. Aluminum is a better rotor material than cast iron due to two main reasons:

1) Its density is as one third as cast iron.
2) Its thermal conductivity is three times greater.

These factors made it possible to construct a much lighter brake disc.

C. Stainless Steel

Stainless steel has many desirable properties that contribute greatly to its widespread application in the making of parts and components across many industrial sectors. Above all, because of its chromium content, it is extremely resistant to corrosion. The 10.5% minimum content makes steel approximately 200 times more resistant to corrosion than steels without chromium. Other favorable properties for consumers are its high strength and durability, its high and low temperature resistance, increased formability and easy fabrication, low maintenance, long lasting, attractive appearance and it is environmentally friendly and recyclable. Once stainless steel is put into service, it does not need to be treated, coated or painted.

1) Corrosion resistant
2) High tensile strength
3) Very durable
4) Temperature resistant
5) Easy formability and fabrication
6) Low-maintenance (long lasting)

D. Ti-6Al-4V

Titanium has excellent properties of weldability, and there is little change in the mechanical properties or corrosion resistance of the welded area. However, at high temperatures titanium has a high affinity for oxygen gas and nitrogen gas, and reaction with these gases may result in hardening and embrittlement which could cause a decline in ductility and the occurrence of blowholes in the welded area. Hence, welding to titanium must be performed in an inert gas or vacuum. In addition, the welding material and electrode, and the welding environment must be cleaned thoroughly before welding. Titanium is normally an active metal, but exhibits extremely high corrosion resistance because a passive film of titanium oxide is generated and is maintained in many environments.

Unlike stainless steel and copper alloys, titanium is not subject to pitting corrosion or stress corrosion cracking, nor to general corrosion. However, titanium is subject to crevice corrosion under high-temperature conditions in highly concentrated solutions. In such cases, it is recommended to use corrosion resistant titanium alloys such as Ti-0.15Pd alloy, AKOT, etc.

E. *Material Properties*

Table 1
MATERIAL PROPERTIES

Properties→ / Material↓	Density (Kg/m^3)	Young's Modulus (GPa)	Poisons Ratio	Thermal Conductivity (W/m-K)	Specific Heat (J/Kg-K)
Grey Cast Iron	7200	110	0.28	52	447
Ti-6Al-4V	4620	95	0.31	7.3	581.58
Aluminum Alloy	2770	71	0.33	144	875
Stainless Steel	7750	193	0.31	15.1	480

V. DESIGN CALCULATIONS

A. *Input Parameters*

In the aspect of car accident prevention, the braking performance of vehicles has been a critical issue. The rotor model heat flux is calculated for the car moving with a velocity 27.77m/s (100kmph) and the following is the calculation procedure.

Data

1) Mass of the vehicle = 300 kg
2) Initial velocity (u) = 27.7 m/s (100 Km/h)
3) Vehicle speed at the end of the braking application (v) = O m/s
4) Brake rotor diameter = 0.2225 m
5) Axle weight distribution 30% on each side (v) = 0.3
6) Percentage of kinetic energy that disc absorbs (90%) k = 0.9
7) Acceleration due to gravity g = 9.81m/s^2
8) Coefficient of friction for dry pavement u = 0.7

B. *Theoretical Calculations*

1) *Step 1*

Kinetic energy (KE) = ½ x m x v^2

=4693.5 joules

The above said the total kinetic energy induced while the vehicle is under motion.

2) *Step 2*

The total kinetic energy = the heat generated

Q_g = 4693.5 joules

3) *Step 3*

The area of the rubbing faces A= π x (0.2225 - 0.1875)

=0.1099 m^2

4) *Step 4*

Heat flux = heat generated/ second / rubbing area = 10676.75 watts/ m^2

C. Calculation for Input Parameters

Table 2
PARAMETERS

Materials / Properties	Formula	Design of disc	Cast Iron	Aluminum Alloy	Stainless Steel	Titanium Alloy
Kinetic Energy	$(m(u-v)^2)/2$	For all models	20958.02 J	20958.02 J	20958.02 J	20958.02 J
Deceleration time	v= u + at	For all models	5sec	5sec	5sec	4 sec
Braking power	P_b = K.E./t	For all models	3493 W	4191.60 W	3945.21 W	4191.60 W
Heat Flux	$Q = P_b/A$	A= 0.03799 m^2	533673.45 W/m^2	1143586.2 W/m^2	547189.3 W/m^2	756642.6 W/m^2

D. Analysis of Materials

1) Grey Cast Iron

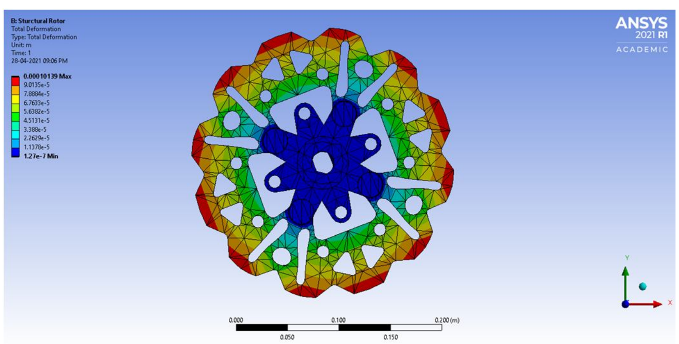

Fig.4. Total Deformation

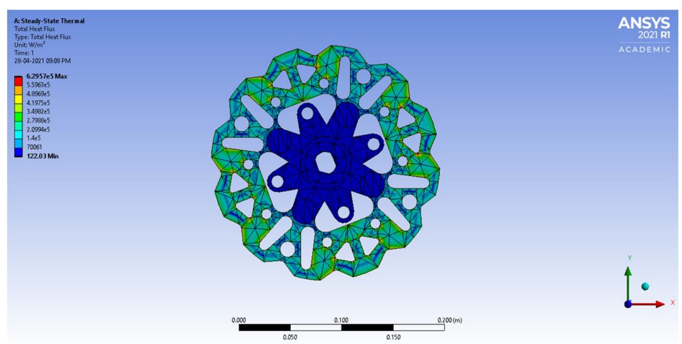

Fig. 5. Total Heat Flux

2) Aluminum Alloy

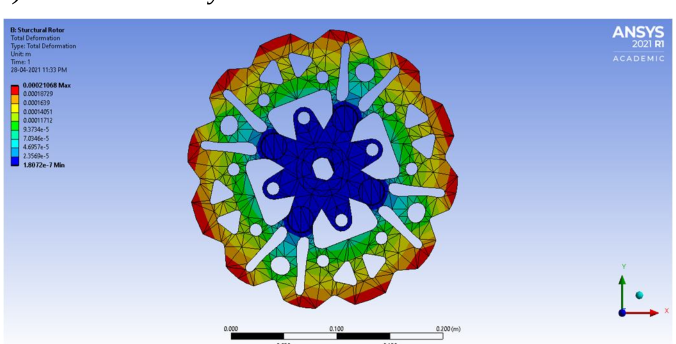

Fig.6. Total Deformation

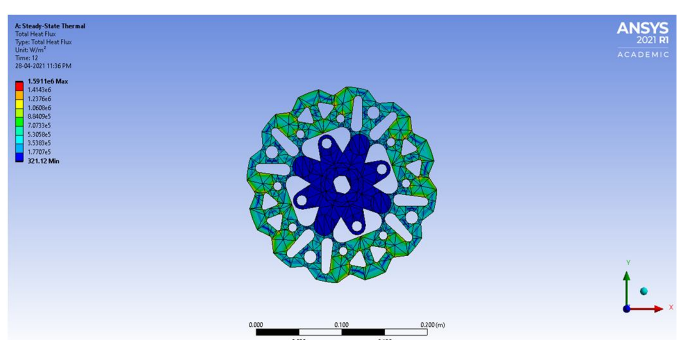

Fig. 7. Total Heat Flux

3) Titanium Alloy (Ti-6Al-4V)

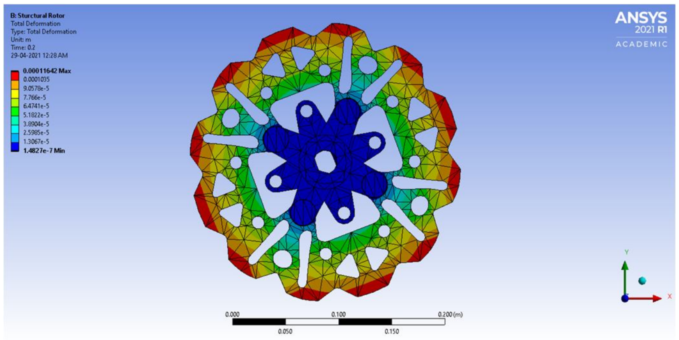

Fig.8. Total Deformation

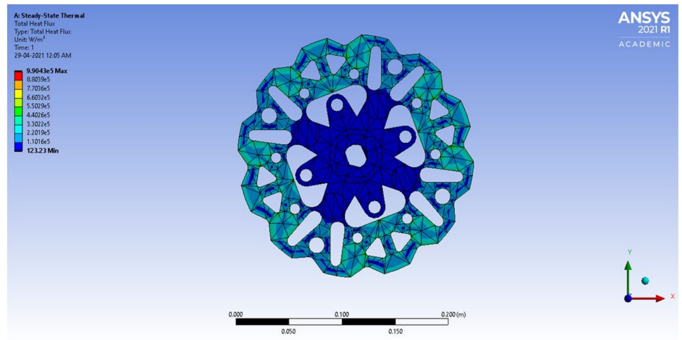

Fig. 9. Total Heat Flux

4) Stainless Steel

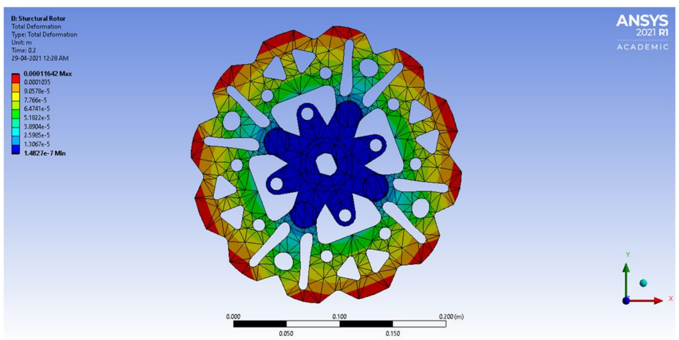

Fig.10. Total Deformation

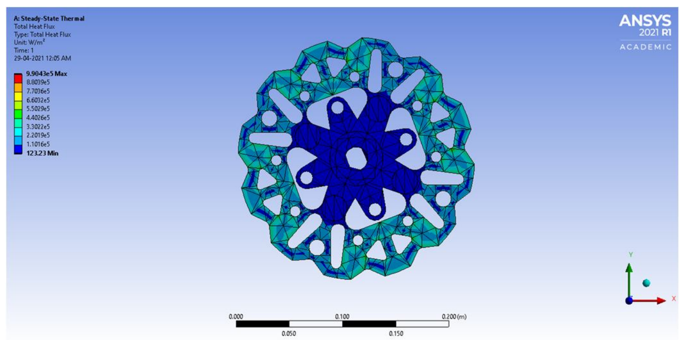

Fig. 11. Total Heat Flux

VI. RESULTS

Table 3
Ansys Analysis Results

Materials	Grey Cast Iron		Aluminum Alloy		Stainless Steel		Titanium Alloy	
Analysis	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Temperature Distribution (^{o}C)	102.3	181.09	220.88	336.87	102.26	285.53	102.87	462.72
Total Heat Flux (W/mm^2)	122.03	6.3X10^5	321.12	1.59x10^6	122.78	6.28x10^5	123.23	9.9x10^5
Total Deformation (mm)	1.27x10^{-4}	1.01x10^{-4}	1.81x10^{-7}	2.1x10^{-4}	1.48x10^{-7}	1.11x10^{-4}	1.06x10^{-7}	7.14x10^{-5}
Equivalent Stress (Pa)	1.20x10^5	1.39x10^9	1.2x10^5	2.66x10^9	1.2x10^5	1.1x10^9	1.15x10^5	4.81x10^8
Equivalent Total Strain	8.59x10^{-7}	6.94x10^{-3}	8.56x10^{-7}	1.33x10^{-2}	8.56x10^{-7}	9.16x10^{-2}	8.14x10^{-7}	3.73x10^{-2}

VII. CONCLUSION

After modelling & meshing we calculate specific perimeter & variable data like as force & moment of inertia static structural result. & heat flux & final temperature for thermal analysis. From our study disc profile for various materials to the maximum temperature rise observed for titanium alloy is 462.72and for stainless steel is 174.2. The maximum temperature rise in cast iron is 181.09 which is less as compared to the titanium alloy, hence it is preferred for moderate load applications. The titanium alloy has the minimum weight of other materials and maximum temperature produce is highest as compare to other materials but it shows good heat dissipation rate. It is costly compared to other materials and cannot machined easily, so it can be used in racing cars where high temperature is produced. The stainless steel has the lowest maximum temperature rise with greatest heat dissipation rate when compared to other materials after cast iron. Comparing the above results obtained from the thermal analysis, it is concluded that stainless steel rotor is the best possible combination for the present application. Total deformation is good, stress, strain is so we can say that Aluminum alloy & titanium alloy is a very good material for brake disc. In this work, a disc-pad model has been analyzed using two approaches, namely mechanical and thermos-mechanical analysis. Aluminum alloy & titanium alloy is a good material too for brake disc from compare to cast iron & structural steel.

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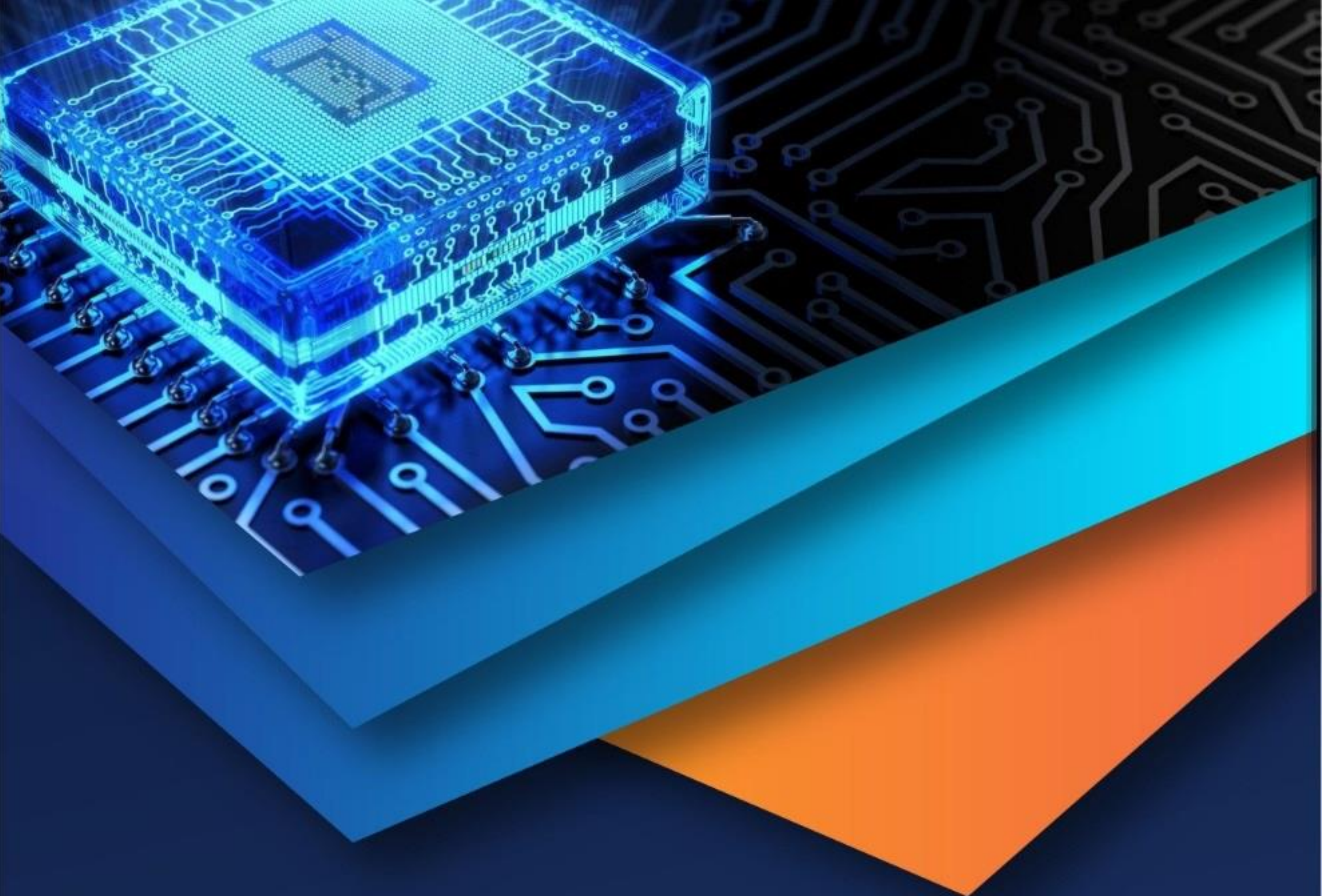

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