

# Modelling and Simulation of Brake Disc for Thermal Analysis

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## Abstract

Brakes being major component in automobiles requires at most attention and advances for road safety. When brakes are applied heat is generated. This heat has to be dissipated very fast to maintain a constant temperature of the brake disc. Maintaining a constant temperature minimizing the thermal fatigue of the brake disc material. Against this background, thermal analysis of various areas and materials of disc brakes is carried out using commercial Ansys Finite volume based CFD Solver the domain is a brake disc of all-terrain vehicle with three materials namely; Grey cast Iron, Aluminum and High speed steel. In addition, the surfaces of the disc were also modified of each disc material by creating various shape hole such as circular, elliptical, oblique-circular, oblique-elliptical, and vanes vents on the surface of disc.

**Keywords:** ATV, Brake Disk, Brake Systems, Circular Vents, Materials

## 1. Introduction

Automotive sector evolves at a very rapid pace and motor-sports is its playground for research and development. Speed and handling are two major factors considered in an automobile. After 100 years of brake disc invention, majority of vehicles still use conventional (drum brakes) braking system<sup>1</sup>. Drum brake are less efficient and less reliable which leads to brake failure. Disc brake was invented in 1903 which is more efficient and reliable as compared to drum brakes. The disc brake design was not evolved and not much study was done to increase its efficiency. Efficiency of the disc brake depends on the design and material of the disc. Copper material was used in the early 20<sup>th</sup> century and ceramic brakes in the early 21<sup>st</sup> century. The research focuses on improving design parameters and materials for off-road All-Terrain Vehicle (ATV) braking system which is capable of rapid heat dissipation without holding thermal stresses in it. All-terrain vehicles was built for harsh, rugged terrains. These terrains, require maneuverability, agility and the ability to stop the vehicle at any instant. A brake disc of 160-mm

was considered for a vehicle weighing 180-kg. Present literature doesn't account for multiple designs or materials, it only shows stress analysis of ventilated brakes of passenger vehicles, thermo-mechanical system of slotted discs and understanding fatigue limit of the brake disc materials<sup>2</sup>. In this respect simulation was conducted on various disc areas and materials to be used in the brake disc of an ATV using Ansys Workbench. The research limits to panic braking in ATV's.

## 2. Material and Methods

Braking system works on pascal's law. When pressure is applied on the disc brake, frictional forces are produced which reduces the speed of the rotating disc. The frictional forces are governed by size and material of the disc brake, interim generating heat. As the rotor size increase so does the contact area with the brake pads. This increases the amount of grip that the caliper pads have thus increasing the frictional forces and braking power<sup>3</sup>. Material of Brake Pad and Disc: Different materials have different properties. Materials govern both the coefficient

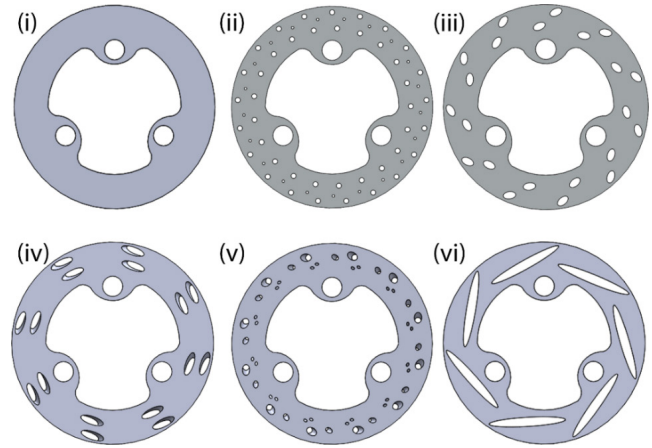
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of friction as-well as the thermal conductivity coefficients. Mathematical model based on data from Table 1 and Table 2<sup>4</sup>.

The contact area of the disc and the caliper is the only source for friction in the brakes. This is widely depended on the materials of both brake disc and caliper pads. Caliper pads can be made of various materials like asbestos, steel, rubber etc. Brake discs are made from ceramics, HSS, Grey iron, aluminum<sup>5</sup>.

Grey Iron is considered mostly for disc brake material. It has high availability and economic inexpensive. However it increases the weight of the vehicle drastically. Advanced materials like ceramics are preferred which is affluent. High speed steel can be considered as an alternative. It withstand high amount of forces and wear which are encountered. HSS has less thermal conductivity when compared to that of the grey cast iron and aluminum. Aluminum can also be one of the alternatives. It has high thermal conductivity and is light weight. However, lacks ability to withstand wear Table 3<sup>4,6</sup>.

Design of the disc brake is kept at high priority. This is done to reduce the thermal stresses generated in it. Aforementioned is achieved by provision of holes in the surface of the disc [2]. Rotors are put through extreme loads when brakes are applied.



**Figure 1.** Brake Disc Computer Aided Designs Geometry with Surface Modifications (i) No Holes (ii) Circular Hole (iii) Elliptical Hole (iv) Oblique Elliptical Hole (v) Oblique Circular Hole (vi) Vanes.

Manuscript highlights reducing the effect of fade present in the brakes. Fade is loss of power. This occurred due to repeated application of brakes. High braking forces and loads are a primary cause for it. To overcome fade, brake discs are designed to dissipate maximum heat in minimum time. We can achieve this by providing ventilations to the brake disc design [7,8]. Solid state brake discs used in

**Table 1.** Limiting factors affecting brake systems

Mass of Vehicle (m)	180 Kg	Stopping Distance Time (t)	3 sec.
Initial Velocity (v)	11.11m/s (40kmph)	Weight Distribution (γ)	0.6
Vehicle speed after brakes (u)	0 m/s	Acceleration due to gravity (g)	9.82m/s <sup>2</sup>
Brake Disc Diameter (D)	160mm	Static Coefficient of Friction (μ)	0.4

**Table 2.** Resultant factors for brake disc analysis

Kinetic Energy Generated	$KE = \frac{1}{2}(mv^2)\gamma = 6665.33J$	Heat Power generated	$P = \frac{KE}{t} = 2221.77W$
Stopping Distance	$d = \frac{v^2}{2\mu g} = 15.71m$	Heat Flux generated	$Q = \frac{4P}{\Pi(D^2 - d^2)} = 197040.5 \frac{W}{m^2}$

**Table 3.** Thermo Physical Properties of Brake Disc Material Considered

Thermo-Physical Properties	Aluminum	Grey Iron	High Speed Steel
Thermal Conductivity (w/m k)	205.0	46	21
Specific heat (J/kg K)	921	460	277
Modulus of Elasticity (GPa)	69	130	210

passenger vehicles having side slotted vane design. These help in quick dissipation of gases and heat. Our research highlights on providing better ventilation system on a single plate disc. Generally used in light weight automobiles like motor bikes and ATV's.

6 Models for the brake discs are considered. (i) No holes (ii) circular hole (iii) elliptical hole (iv) oblique elliptical hole (v) oblique circular hole (vi) vanes Figure 1.

When brakes are applied the friction factor results in generation. High amounts of heat which are built up on the brake disc cause brake failure. Brake discs have to be cooled to reduce effects of fade. Literature and experiments shows higher temperature leads to high co-efficient of friction<sup>3</sup>. This increases the stopping distance. Rotors heat a pocket of gaseous mixture leading to better co-efficient of friction. Before a limit called the keeling point [4, 9-11].The disc in many cases is pre -heated for better efficiency. However pre-heating temperature exceeding limits causes judder and high vibrations [2]. Which leads to fade and deformation.<sup>3, 4 & 12</sup>.

### 3. Mathematical Modelling

Computational fluid dynamics help us understand the fluid mechanics. These help is better understanding of fluid systems acting on the disc [2, 3 & 13]. Following the conservation of energy model. Kinetic energy is being converted into heat energy. This is done by the frictional forces applied on the surface of the disc. Making a steady state transient model analysis of the disc was carried out on the Ansys Workbench. Research focuses on the 3 materials (i) Aluminum Alloy (ii) Grey Cast Iron (iii) High Speed Steel. CAD models are imported into the workbench. Un-structured mesh is created in the workbench. The boundary condition is applied Table 4. The flow diagram of simulation processes was shown in Figure 2.

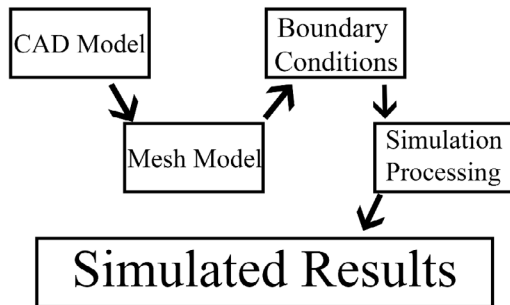


Figure 2. Work Process Flow Chart For Finite Volume Solution.

Surface of the brake rotor taking in account heat flow, insulation and convection (Figure 3 and 4 and Table 4). The surface in contact with the rotor and the pad the rate of heat generation is calculated by:

$$dE = dP = VdF_f = r\omega\mu p\phi r dr \tag{1}$$

$$dE = dE_p + dE_d \tag{2}$$

$$dE_p = (1 - \sigma)dP = (1 - \sigma)\mu p\omega\phi r^2 dr \tag{3}$$

$$dE_d = \sigma dP = \sigma\mu p\omega\phi r^2 dr \tag{4}$$

Where  $dE$  is the rate of heat generation due to friction between two sliding components<sup>3</sup>.

$V$  is the relative sliding velocity and  $dF_f$  is the frictional force<sup>7</sup>. The terms  $dE_p$  and  $dE_d$  are the amount of absorbed heat by the pad and the disc respectively<sup>6</sup>.

Table 4. Boundary Conditions for disk brake

1	Brake Surface	Heat Flow	2222.2 W
2	Holes and Side Surface	Convection	10 W/m <sup>2</sup>
3	Mounting Points	Perfectly Insulated	0 W

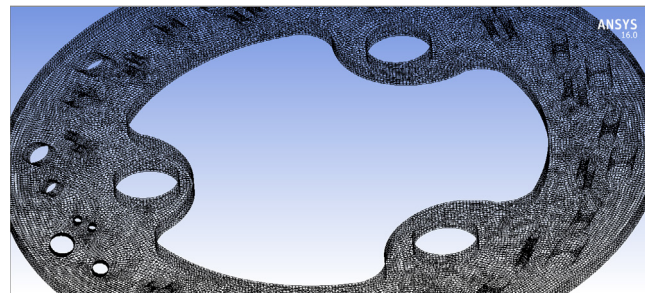


Figure 3: Unstructured meshing for disc brake

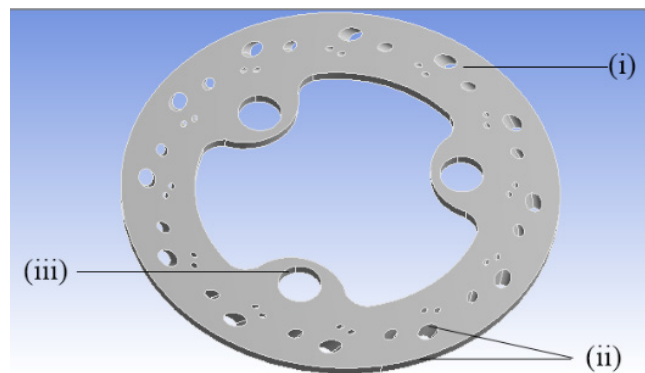


Figure 4: Physical domain for Brake Disk (i) Heat flow zone (ii) Convection zone (iii)

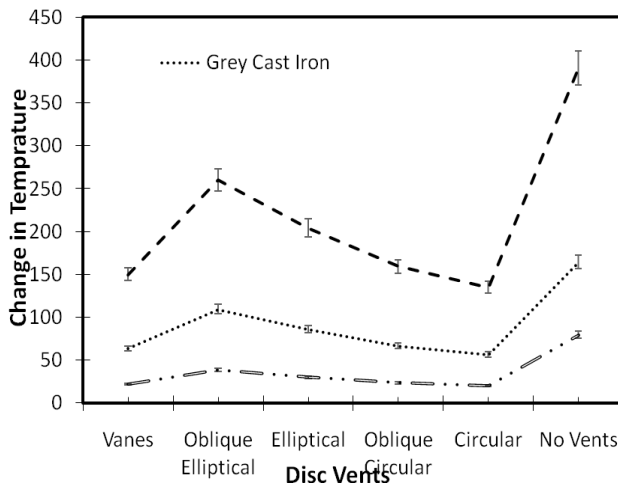


Figure 5. Brake Disk Vent VS Temperature Drop.

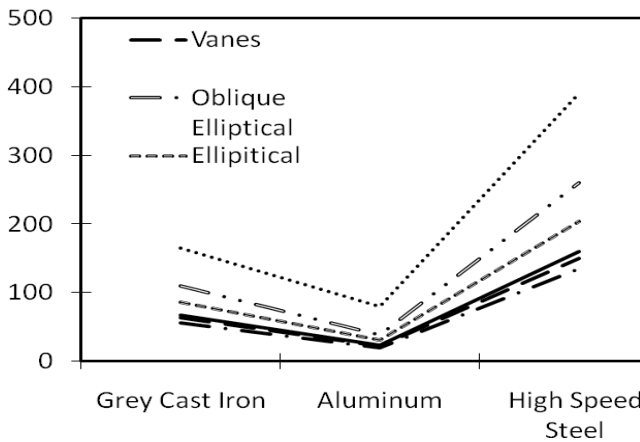


Figure 6. Variation of Temperature Difference with Material.

The brake disc must have the ability to transmit heat fast. While maintain a low temperature after applica-

Table 5. Temperature Difference of Various Materials With Respect to Contact Surface Area

Disk Type	Volume(mm <sup>3</sup> )	Surface Area (mm <sup>2</sup> )	Grey Cast Iron	Aluminum	High Speed Steel
			Temp Difference(°C)	Temp Difference(°C)	Temp Difference (°C)
Vanes	39965.99	27463.68	63.550	22.165	150.00
Oblique Elliptical	43703.40	28830.53	109.530	38.377	259.93
Elliptical	45814.89	29102.27	86.048	30.165	204.30
Oblique Circular	46481.28	30246.48	67.081	23.534	159.28
Circular	47304.93	30312.26	56.573	19.938	134.85
No Vents	49679.97	30312.26	164.62	79.679	390.98

tion of brakes. This is largely dependent on the material selection effecting the thermal conductivity and mode of convection.

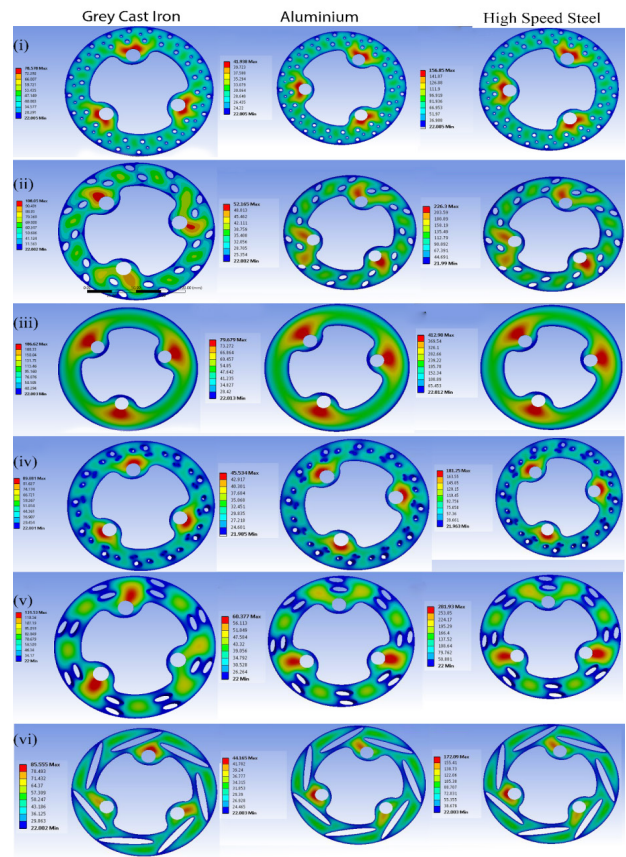


Figure 7. Result Simulations for (i) Circular Vents (ii) Elliptical Vents (iii) No Vents (iv) Oblique Circular Vents (v) Oblique Elliptical Vents (vi) Vanes.

Results clearly show that circular disc has the best temperature drop (Figure 5). No hole-plain disc shows minimum temperature difference. Material assessment shows aluminum showing fastest heat dissipation. High speed steel has very poor thermal (Figure 6 and 7).

Surface area and contact volume of the disk is a small factor. This does not affect the temperature difference adversely. Material and hole design is the governing factor for the heat dissipation (Table 5). High contact area and volume constitute for better heat dissipation with better ventilation designs.

Ventilations provide the best mode of heat loss. Circular holes providing maximum temperature drop. Elliptical holes can be selected at second best. No ventilation plain discs provide poor results. Minimum heat dissipation is present. This is not desired in the design. It is reported that dynamic friction factor depends on the temperature. Which is more effective when thermal temperature of disk is high however temperature is a function of time. Through various post processing it is found that ventilations are a very essential part of the brake rotor to function it properly. Cooling can be achieved with circular ventilations provided over the disc surface. In this context circular ventilations with aluminum provide the best temperature drop.

## 4. Conclusions

Shape factor adversely affects the cooling of the brake disc. This not only helps in uniform thermal distribution. It also restricts growth of thermal stresses in the rotor. Heat dissipation is a key factor effecting many engineering parameters. These can be addressed with such surface extrusions. Exposing the affected area to convection also reduces thermal stresses. These hinder proper performance and disturb the material properties. Which can cause devastating effects. In this context it is noted that majority of performance vehicles have circular holes on the brake disc surface. These ventilations can be used in many other engineering activities like electrical enclosures, nuclear reactors and heat sinks.

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