Design and Optimization of Disc Brake Using FEA

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Abstract
One of a car's most crucial active safety elements is the disc brake unit, which is situated at the front axle. An essential part of the disc brake system is the brake disc rotor. The rate of friction between the brake pads and the rotor and the amount of heat released into the air define how effective this braking system is. It could harm the brake mechanism and cause it to overheat due to thermal stress which would cause the brake system to break down. Grey cast iron, stainless steel, and aluminium were the three main types of materials used in this study. In addition, three designs solid, semi-ventilated, and ventilated disc were applied in this investigation. As for design and analysis, thermal analysis and Solidworks were used. Based on the results, the ventilated disc brake is the best design in terms of heat transfer. Aluminium is a material with good heat distribution but cast iron can be consider as an option for production.

Keywords: Disc brake, Thermal analysis, Heat dissipation.

1.0 Introduction
The disc brake unit, which is placed at the front axle, is one of the most crucial active safety components on an automobile. The disc braking system's brake disc rotor is a

crucial component. The braking system must be effective enough to offer predictable and safe stopping in order to drive safely. With the aid of a brake calliper mechanism, friction material-filled brake pads are to be hydraulically forced onto the disc rotor on both sides. The amount of heat released into the environment determines how well the braking system works, the thermal stress generated due to friction between the pads and the rotor can lead to braking system failure. A set of brake pads are forced against a rotating disc in a disc brake system, and heat is produced at the disc-pad interface as a result of friction. The kinetic energy produced by the brakes is absorbed and released into the atmosphere as heat [1].

Both stainless steel and grey cast iron produced at sufficiently high temperatures by the solid disc brakes. This includes a greater amount of metal, which helps to regulate temperature changes and lowers the risk of disc distortion brought on by excessive heat [2].

(a) (b)

Figure 1: (a) Solid Disc (b) Ventilated Disc

Due to its additional heat-dissipating surfaces, the vented brake disc is a better alternative. Heat transmission is significantly impacted by the design of disc brakes. It would be fascinating to observe how the thickness and variety of vanes effect temperature distribution [3].

Cast iron with enough hardening capacity is used for analysis. Cast iron contains carbon in amounts more than 2% [4-5]. It is more economical when used as a disc material and has better castability and machining ability, excellent thermal conductivity and heat capacity. It also resists fade on brakes. In accordance with the findings of the temperature investigation, the amount of temperature created in the vented cast iron is noticed. The disc produces heat that is 187 Kelvin less than the temperature of the air around it [6]. Due to their excellent corrode resistance, capability to maintain mechanical and chemical characteristics at higher temperatures, thermal and electric stability and low market costs, both stainless steel and grey cast iron are widely utilized in the automobile sector. The minimum temperature for grey cast iron is 10.9% greater than it is for stainless steel. Additionally, compared to stainless steel, total heat flux of grey cast iron has a total heat flux that is 9.02% higher [7].

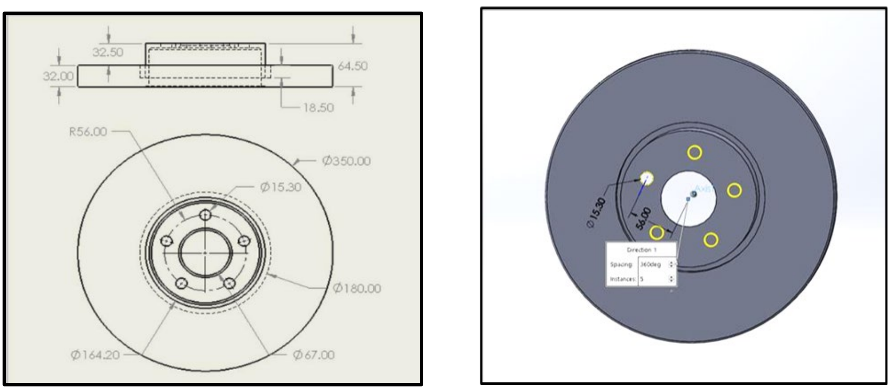
As temperatures rise and thermal stresses develop in an automobile disc brake during braking, the disc material may be adversely affected, eventually resulting in an overheated disc brake and the start of a crack [8]. Although these impacts might appear insignificant for a little car, they can have a big influence, especially when the car is moving. The energy needed to stop a vehicle is rising dramatically due to the present trend in vehicle development toward faster moving and larger loads. The disc braking system produces the most heat while losing the least heat [9-10]. The primary goals of this research are to conceptually design a disc brake rotor and examine how the rotor disc's temperature is distributed.

2.0 Methodology

The disk brake in this study is constructed via Solidworks software. The dimensions use for the disc brake is benchmark from the research on disc brake design (Brembo disc) as shown in Table 1.

Table1: Dimension parameter

Item	Dimension
Diameter of Outer disc	350 mm
Diameter of Inner disc	164.2 mm
Thickness of Disc	32 mm
Height of Disc	64.5 mm
Diameter of Clamp hole	15.30 mm
Number of clamp holes	5
Diameter of Circle slot	180 mm



(a) (b)

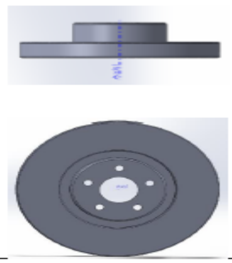
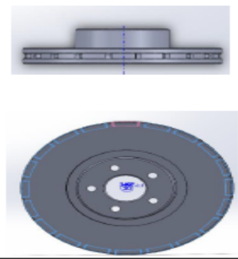
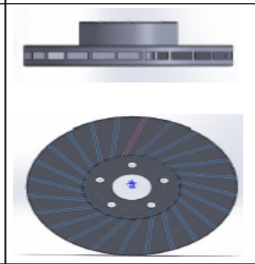
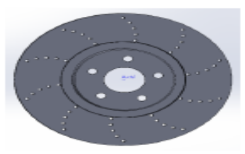
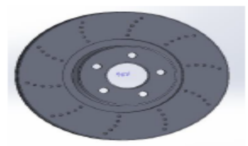
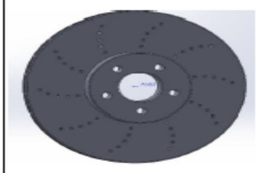
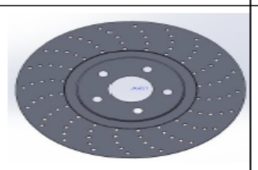
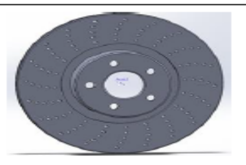
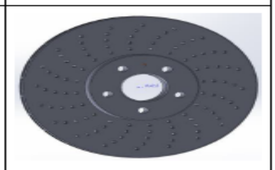
Figure 2: (a) Schematic design of disc brake, (b) 3D disc brake model

The new design was created in order to address the previous solid disc brake's limitations in heat dispersion performance after the original model was simulated and the results were analyzed. The parameters for this study are given in Table 2 and model of the disc brakes as in Table 3.

Table 2: Parameter for disc brake

Parameter	Value
Design Disc Brake	Solid, Semi-ventilated and Ventilated
Thickness of Disc Brake	3, 6 and 9 mm
No of holes on Disc Brake	0, 50 and 100 holes

Table 3: Disc brakes model

Design / Thickness	SOLID DISC BRAKE	SEMI VENTILATED DISC BRAKE	VENTILATED DISC BRAKE
Reduced 3mm (Disc 1)			
Reduced 6mm (Disc 2)			
Reduced 9mm (Disc 3)			

The materials use for analysis are grey cast iron, stainless steel, and aluminium. The properties of material are as shown in Table 4. Disc brake heat distributions can be created and analyzed using Ansys program, one of finite element software. Due to the dynamic nature of braking, the brake disc rotors used in this study underwent transient thermal analysis.

For the purpose of this study, the vehicle's mass (m) is 1000 kg, its maximum and minimum speeds (u and v) are 100 km/h and 0 km/h, respectively, and the stopping time of the disc is 6 seconds.

Table 4: Properties of material

Characteristics/ Material	Grey Cast Iron	Stainless Steel	Aluminium Alloy
Density	$7.2x10^{-6}$ kg/mm^3	$7.75x10^{-6}$ kg/mm^3	$2.77x10^{-6}$ kg/mm^3
Young's Modulus	$1.1x10^5$ MPa	$1.93x10^5$ MPa	71000 MPa
Thermal Conductivity	0.052 $W/mm.^0C$	0.0151 $W/mm.^0C$	0.14862 $W/mm.^0C$
Specific Heat	$4.47\ x10^5$ $mJ/kg.^0C$	$4.8\ x10^5$ $mJ/kg.^0C$	$8.75\ x10^5$ $mJ/kg.^0C$

3.0 Result and Discussion

The simulation and analysis were designed to determine the effect of the four factors on the model.

3.1 Solid Disc

The temperature distribution of solid disc brakes 1, 2, and 3 of different materials is shown in Table 5.

Table 5: Temperature of optimized solid discs

Material	Solid Disc 1		Solid Disc 2		Solid Disc 3	
	Temperature (^0C)					
	Max	Min	Max	Min	Max	Min
Grey Cast Iron	144	21.31	144	21.307	144	19.867
Stainless Steel	190	11.349	190	13.203	190	20.502
Aluminiu m Alloy	129	22.005	129	22.004	129	22.005

The stainless steel solid discs 1 have the lowest temperature because stainless steel's capability to conduct heat and release heat more effectively than other materials. In a contrast with stainless steel and grey cast iron, aluminium alloy is not as effective in dissipating heat and transfers heat because the differences of temperature are the lowest.

3.2 Semi Ventilated Discs

The semi ventilated discs temperature distribution is shown in Table 6. From the result, it shows that the lowest temperature is 15.964°C, which from Semi Ventilated disc 1 using stainless steel. The minimum temperature differences are from semi ventilated disc using aluminium alloy with constant minimum temperature's result, 22.006°C. Meanwhile, for solid disc 1, 2 and 3 of grey cast iron consider to be in the middle of stainless steel and aluminium alloy in minimum temperature.

Table 6: Temperature of optimized semi ventilated discs

Material	Semi Ventilated Disc 1		Solid Ventilated Disc 2		Solid Ventilated Disc 3	
	Temperature (^{0}C)					
	Max	Min	Max	Min	Max	Min
Grey Cast Iron	144	21.35	144	21.151	144	20.6
Stainless Steel	190	15.96	190	20.583	190	20.3
Aluminium Alloy	129	22.01	129	22.006	129	22.0

3.3 Ventilated Discs

According to Table 7, the minimum temperature for each material in a vented disc varies. In comparison to other disc brake models, the ventilated disc 3's -2.4178°C lowest temperature is also thought to be the lowest temperature. In vented disc 1 made of stainless steel, record the second-lowest temperature of 1.3529 °C. The overall trend of the lowest temperature for both grey cast Iron and stainless steel are decrease, but not for the alloy of aluminium.

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Table 7: Temperature of ventilated discs

Material	Ventilated Disc 1		Ventilated Disc 2		Ventilated Disc 3	
	Temperature (^{0}C)					
	Max	Min	Max	Min	Max	Min
Grey Cast Iron	144	14.3	144	17.399	144	15.51
Stainless Steel	190	-1.35	190	1.6549	190	-2.417
Aluminium Alloy	129	22.8	129	22.806	129	22.80

3.4 Total of Heat Flux

According to Table 8, the total heat flux rises steadily for each design. The highest total heat flux is displayed by a ventilated disc, whereas the lowest is shown by a solid disc. When compared to stainless steel and grey cast iron, the total heat flux of aluminium alloy is the highest.

Table 8: Total of heat flux

Disc Brake	Total Heat Flux (W/mm^2)		
	Grey Cast Iron	Stainless Steel	Aluminium Alloy
Solid disc 1	0.13882	0.089065	0.58476
Solid disc 2	0.21383	0.055456	0.63858
Solid disc 3	0.21869	0.036391	0.58851
Semi ventilated disc 1	0.13947	0.10216	0.57851
Semi ventilated disc 2	0.18126	0.059937	0.62852
Semi ventilated disc 3	0.22844	0.057804	0.64291
Ventilated disc 1	0.77756	0.49188	1.2319

Ventilated disc 2	0.76375	0.49665	1.1788
Ventilated disc 3	0.72455	0.48879	1.1339

*disc 1(no hole, -3mm), disc 2 (50 hole, -6mm), disc 3 (100 hole, -9mm)

4.0 Conclusion

The temperature distribution and the total heat flux have been compared on all the design and finally the conceptual design for disc brake is identify. Based on results, the ventilated disc brake made of aluminium alloy is the best design in terms of heat transfer where it can dissipate the heat quickly. The disc's geometric structure and material play an essential role in enhancing the disc cooling process. Although aluminium alloy is a good material but it is very costly to be on production. Therefore, grey cast iron can be the other option as it is also good in heat distribution.

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Author Contributions

N. Chik: Software, Design, Data collection; **B. Zubir:** Supervision, Validation, Conceptualization, Methodology; editing; **A.F.A. Rahman;** Result interpretation, Writing and editing.

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