Heat Analysis of Various Materials for a Braking System

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Abstract - *The aim of the paper is to give heat analyses of various materials for a braking system of a formula student vehicle . Braking system is the safety system of the vehicle which is used to put the moving motion of a vehicle to stop. The stopping force helps in converting kinetic energy into heat energy and the analysis of the same is done in this paper. In a Formula Student vehicle where a disc brake is used, due to heat generation it can change certain properties of the brake disc and it can damage which will be a serious problem for the vehicle.*

Keywords—*Brake disc, heat analysis, braking system, aluminum, SS410, Titanium Grade V.*

1. INTRODUCTION

Formula Student is a competition held globally among the engineering colleges in which undergraduate students design, analyse, manufacture, test and race a combustion or an electric vehicle made according to certain given rules of the event. The braking system is defined as changing kinetic energy into heat energy. The main purpose of the brake system is controlling speed, and the rate of dissipation of energy defines the vehicle's deceleration rate. Braking system can be divided into sprung mass and unsprung mass. The sprung mass includes the pedals, master cylinder, reservoir and the unsprung mass includes brake disc, caliper.

Brake system performance significantly affects safety, handling and vehicle dynamics. Therefore, the objective of this paper is to discuss brake system characteristics and performance and component design parameters. This paper designs and models the generation of heat and its dissipation in a brake disc of a formula student vehicle during hard braking. The maximum allowable force to the pedal is 2kN according to the FS rulebook. If the brake disc overheats the braking system starts to malfunction and can damage the brake disc.

2. DESIGN OF BRAKE DISC

The design process starts with the selection of calipers. After various considerations and research on several factors like bore diameter, piston diameter, reliability and finance Wilwood caliper was selected from a list of calipers like Brembo, Tilton etc. There are two types of brake calipers that are floating and fixed. In which two types of brake disc can be used floating and fixed brake disc. We are using a floating type brake disc because it has less heat transfer rate from outer disc to hub because of Bobbin. Bobbin is used for mounting brake discs on hubs. The brake disc size is selected on the basis of caliper and the range of rotor diameter which is already provided by the company for the specific caliper.

We decided to use the Wilwood caliper PS1 based upon our above given considerations which has a rotor diameter range of 6 inches to 9 inches. So according to the selection of calipers, our brake rotor diameter is 6.7 inches.

Slots and holes are designed to increase the heat transfer rate if the slots and holes are not provided it will increase the temperature of the disc which will in turn decrease coefficient of friction which may result in brake failure and to reduce weight of the brake disc.

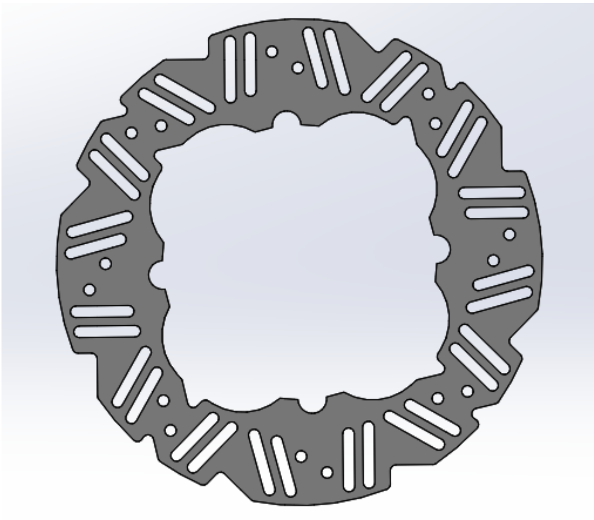

Fig 1:- Final Design of disc

3. Heat flux of brake disc for SS410 :

Given (According to our design):-

Table -1: Given data for SS410

Density of disc (δ_D)	7850 kg/m³
Density of pad (Silicon Carbide) (δ_P)	3210 kg/m³
Thermal Conductivity of disc (K_D)	23 W/mK

Thermal conductivity of pad (K_P)	60 W/mK
Specific heat of disc (C_D)	450 J/kgK
Specific heat of pad (C_P)	510 J/kgK
Outer radius of pad from centre (OR)	0.085 m
Inner radius of pad from centre (IR)	0.065 m
Surface area of pad (S_P)	0.00129 m^2

Thermal diffusibility of disc (ε_D) $=K_D/\delta_D*C_D$

$=6.51*10^{-6}\ m^2/s$

Thermal diffusibility of pad (ε_P) $= K_P/\delta_P*C_P$

$=3.66*10^{-5}\ m^2/s$

Contact Area of pad on disc (S_D) $= \pi(OR^2-IR^2)$
$= 0.00942\ m^2$.

Heat Partition Coefficient($\boldsymbol{\sigma}$)$=\varepsilon_D* S_D/[(\varepsilon_D* S_D)+(\varepsilon_P* S_P)]$ = 0.564

Table -2: Working parameters

Coefficient of friction ($\boldsymbol{\mu}$)	0.45
Arc Length of pad (Φ)	0.628 m
Velocity (v)	9.31 m/s
Pressure on pads (P_P)	$23*10^4$ Pa
Effective Radius of disc (R)	0.075 m

Angular Velocity (ω) = v*R
= 0.69 rad/s

Heat Flux $= (\Phi/2\pi)*\boldsymbol{\sigma}*\boldsymbol{\mu}*\varepsilon_P*\omega$
$= 2615.426\ W/m^2$

4. Heat Flux of brake disc for Titanium Grade V

Given (According to our design):-

Table -3: Given data for Titanium Grade V

Density of disc (δ_D)	4430 kg/m^3
Density of pad (Silicon Carbide) (δ_P)	3210 kg/m^3
Thermal Conductivity of disc (K_D)	6.7 W/mK
Thermal conductivity of pad (K_P)	60 W/mK
Specific heat of disc (C_D)	526 J/kgK
Specific heat of pad (C_P)	510 J/kgK
Outer radius of pad from centre (OR)	0.085 m
Inner radius of pad from centre (IR)	0.065 m
Surface area of pad (S_P)	0.00129 m^2

Thermal diffusibility of disc (ε_D) $=K_D/\delta_D*C_D$

$=2.87*10^{-6}\ m^2/s$

Thermal diffusibility of pad (ε_P) $= K_P/\delta_P*C_P$

$= 3.665*10^{-5}\ m^2/s$

Contact Area of pad on disc (S_D) $= \pi(OR^2-IR^2)$
$= 0.00942\ m^2$

Heat Partition Coefficient($\boldsymbol{\sigma}$)$=\varepsilon_D* S_D/[(\varepsilon_D* S_D)+(\varepsilon_P* S_P)]$

= 0.364

Table -4: Working parameters

Coefficient of friction ($\boldsymbol{\mu}$)	0.45
Arc Length of pad (Φ)	0.628 m
Velocity (v)	9.31 m/s
Pressure on pads (P_P)	$23*10^4$ Pa
Effective Radius of disc (R)	0.075 m

Angular Velocity (ω) = v*R
=0.69 rad/s

Heat Flux $= (\Phi/2\pi)*\boldsymbol{\sigma}*\boldsymbol{\mu}*\varepsilon_P*\omega$
$= 1686.92\ W/m^2$

5. Heat Flux of brake disc for Aluminium Silicon Carbide :-

Given (According to our design) :-

Table -5: Given data for Aluminium Silicon Carbide

Density of disc (δ_D)	2900 kg/m^3
Density of pad (Silicon Carbide) (δ_P)	3210 kg/m^3
Thermal Conductivity of disc (K_D)	130 W/mK
Thermal conductivity of pad (K_P)	60 W/mK
Specific heat of disc (C_D)	800 J/kgK
Specific heat of pad (C_P)	510 J/kgK
Outer radius of pad from centre (OR)	0.085 m
Inner radius of pad from centre (IR)	0.065 m
Surface area of pad (S_P)	0.00129 m^2

Thermal diffusibility of disc (ε_D) $=K_D/\delta_D*C_D$

$=5.603 * 10^{-5}$ m^2/s

Thermal diffusibility of pad (ε_P) $= K_P/\delta_P*C_P$

$= 3.665 * 10^{-5}$ m^2/s

Contact Area of pad on disc (S_D) $= \pi(OR^2-IR^2)$
$= 0.00942$ m^2

Heat Partition Coefficient($\boldsymbol{\sigma}$)$=\varepsilon_D* S_D/[(\varepsilon_D* S_D)+(\varepsilon_P* S_P)]$
$= 0.9177$

Table -6: Working parameters

Coefficient of friction (**μ**)	0.45
Arc Length of pad (Φ)	0.628 m
Velocity (v)	9.31 m/s
Pressure on pads (P_P)	23*10^4 Pa
Effective Radius of disc (R)	0.075 m

Angular Velocity (ω) = v*R
= 0.69 rad/s

Heat Flux $= (\Phi/2\pi)* \boldsymbol{\sigma}*\boldsymbol{\mu}*\varepsilon_P*\omega$
$= 4250$ W/m^2

6. MESH OF THE BRAKE DISC

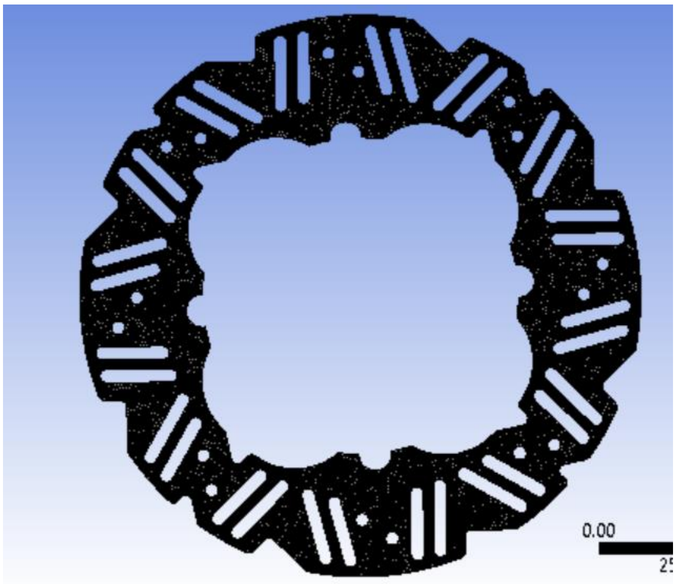

Fig 2 :- Total mesh of brake disc

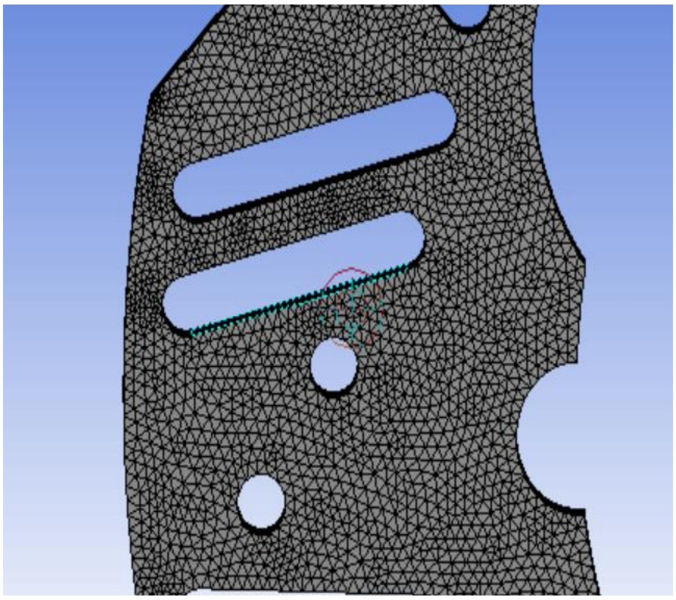

Fig 3 :- Small part preview of brake disc mesh

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7. ANSYS OF BRAKE DISCS FOR THE ABOVE ENLISTED MATERIALS

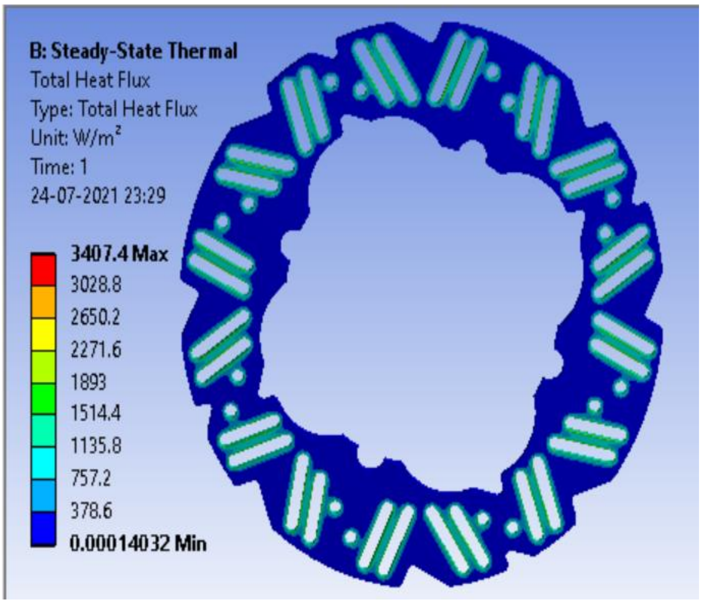

Fig 4 :- SS410 total heat flux

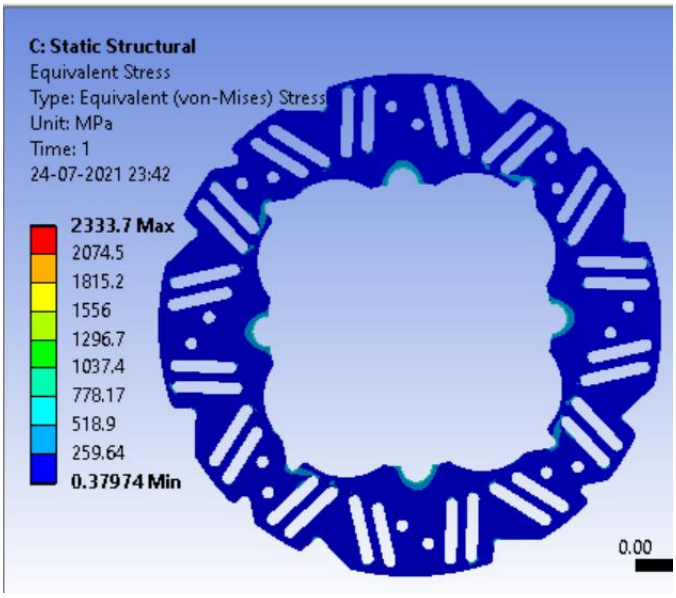

Fig 5 :- SS410 stress

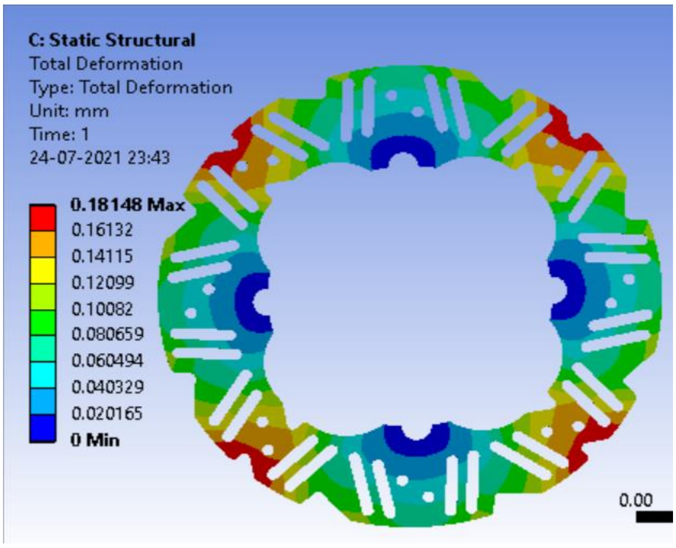

Fig 6 :- SS410 deformation

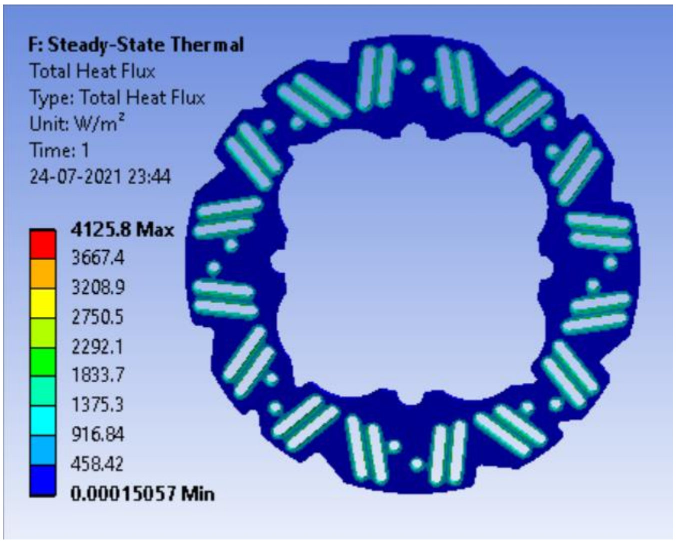

Fig 7 :- Titanium grade V total heat flux

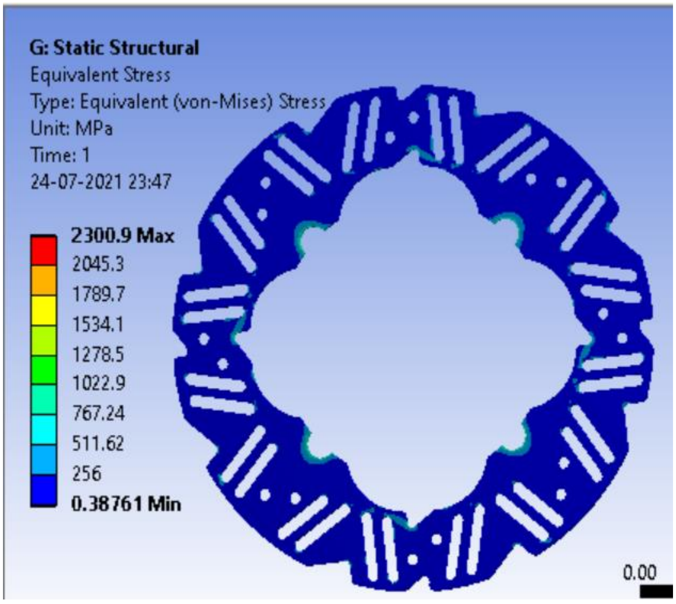

Fig 8 :- Titanium grade V stress

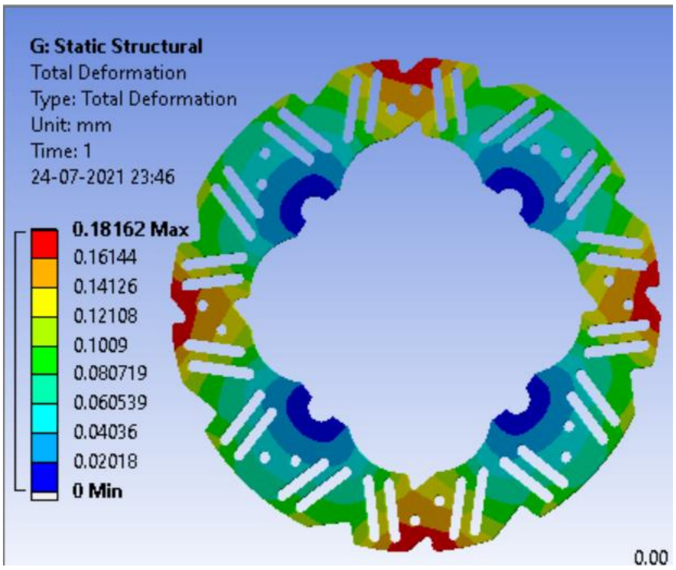

Fig 9 :- Titanium grade V deformation

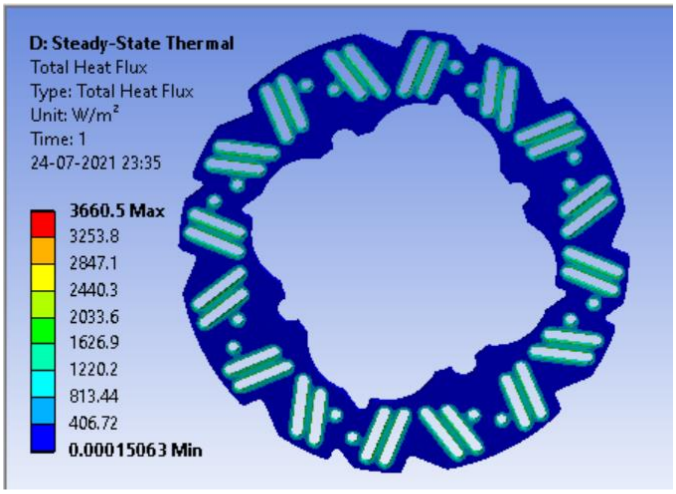

Fig 10 :- Aluminium total heat flux

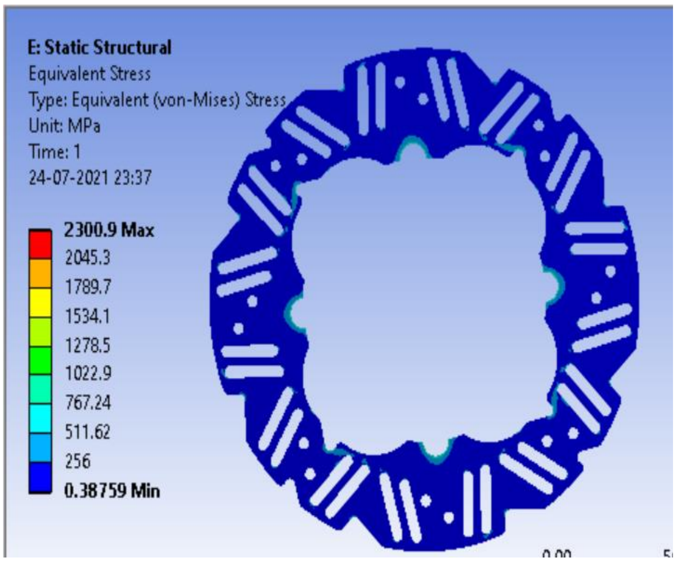

Fig 11 :- Aluminium Stress

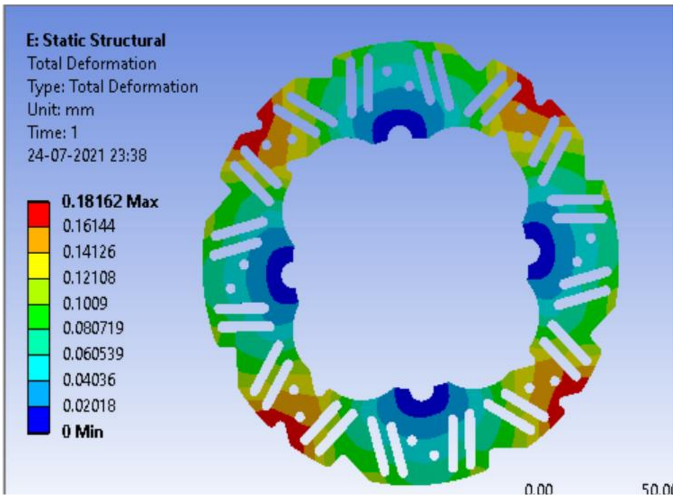

Fig 12 :- Aluminium deformation

8. RESULT

Table -6: Result table

MATERIAL	TITANIUM	SS410	ALUMINUM SILICON CARBIDE
HEAT FLUX	1686.92 W/m^2	2615.426 W/m^2	4250 W/m^2
WEAR	LOWEST	MODERATE	HIGH
COST	2000/kg	500/kg	1500/kg

9. CONCLUSIONS

1) As per our result from ansys and our theoretical calculations it was deduced that Aluminium Silicon Carbide shows the best possible heat dissipation which is one of the most significant characteristics of a brake disc but shows more wear. Therefore Aluminium cannot be classified as the ideal material for a FS vehicle.

2)Although Titanium Grade 5 shows low rate of wear but it has low heat dissipation and high cost it cannot be classified as a good material for brake disc in FS vehicles.

3) SS410 has less wear rate and also the heat dissipation provided by SS410 is slightly less than Aluminium Silicon Carbide material. This makes SS410 the most viable material for formula student vehicles.

10. FUTURE SCOPE

1) The brake system can be combined with aerodynamics to increase the cooling and heat dissipation of the brake discs.

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