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STRUCTURE & THERMAL ANALYSIS OF DISK PLATE FOR TWO WHEELER AUTOMOTIVE FRONT DISK BRAKE

Pankaj Pathak [*1], Asst. Prof Anshul Choudhary, Prof. K.K. Jain [2]
*Mechanical Department, S.R.I.T. Collage, India

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ABSTRACT

A Disc brake is a device that retards/halts the rotation of a shaft/ wheel. A disc brake system consists of a brake disc, a brake caliper and brake pad. When the brake pedal is applied, pressurized hydraulic fluid squeezes the brake pad friction material against the surface of the rotating brake disc. The result of this contact produces friction which enables the vehicle to slow down or stop. Due to this friction, heat will be generated and the brake disc gets heated up which affects the performance of the disc brake under different braking conditions. In this paper focus is primarily emphasized on the comparative performance of disc brakes having different profiles, by determining the von-misses stress, deformation developed & Maxi heat dissipation in the brake disc for different braking conditions using ANSYS14.5.

In this work Gray Cast Iron & Structure Steel disc brake material use for calculating von-misses stress & deformation. The standard disc brakes two wheelers model using in Ansys and done the Modal analysis & calculate the Stress, deformation & Maxi heat dissipation. This is important to understand Stress, Deformation & Heat dissipation on the disc plate, how disc brake works more efficiently, which can help to Increase life of the disk plate & to find best profile structure of the disk plate.

KEYWORDS: Disc , ANSYS14.5, Structure, & Maxi heat dissipation.

I. INTRODUCTION

The Drum brake is not sufficient for excessive heat condition, requires more effort from rider and needs to be adjusted frequently. To overcome above problems disc brake is used. A disc brake uses hydraulic pressure to stop the vehicle. It is widely used in motorcycles, cars, trucks, buses, bicycle etc. but here we are focusing only on motorcycle disc brake.

The first caliper-type automobile disc brake was patented by Frederick William in 1902 but it was failed due to use of copper disc. The first motorcycles to use disc brakes were racing machines. The first mass-produced road-going motorcycle to support a disc-brake was the 1969 Honda CB750. (A Successful motorcycle launched by Honda)

A Brake is a device used in the machines to inhibit the motion by providing artificial frictional Resistance to a moving member. Brake plate absorbs the kinetic energy and dissipates the heat energy. There are different types of brakes among which disc brakes, drum brakes, air brakes, and vacuum brakes are prominent. The disk brake is a round, flat piece of metal, made usually of cast iron that is attached to the wheel. When braking, the brake discs are squeezed against the wheel on either side by brake pads. Disk brakes are more effective than drum brakes.

Disc brakes

Disc brakes use a flat, disk-shaped metal rotor that spins with the wheel. When the brakes are applied, a caliper squeezes the brake pads against the disc just as you would stop a spinning disc by squeezing it between your fingers, and slows the wheel.

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A disk brake works on the principle of Pascal's Law .The fluid enters in to cylinder bore of caliper assembly via brake hosepipes and pushes the caliper piston. At this time the piston ring moves in rolling shape with piston and then the caliper piston pushes brake pad. This movement causes brake pads to stick with brake disc which creates friction and stops the brake disc/rotor to rotate by which the disk brake system stops or slows down the vehicle.

When the brake lever is released the piston ring pushes the caliper piston back to cylinder bore of caliper till both, caliper piston and piston ring come into their original shape. At this time retraction spring pushes the brake pads to their original position. The return spring in master cylinder assembly pushes the It's cylinder piston back into its original position and allows the fluid to flow

II. MATERIALS AND METHODS

Properties of Gray Cast Iron

As Per Ansys Data

DESCRIPTION	VALUE	UNITS
Density	7.2e-006	kg /mm^3
Compressive Ultimate Strength	820	MPa
Tensile Ultimate Strength	240	MPa
Poisson's Ratio	0.28	

Properties of Steel

DESCRIPTION	VALUE	UNITS
Density	7.85e-006	kg /mm^3
Compressive Yield Strength	250	MPa
Tensile Ultimate Strength	460	MPa
Poisson's Ratio	0.3	

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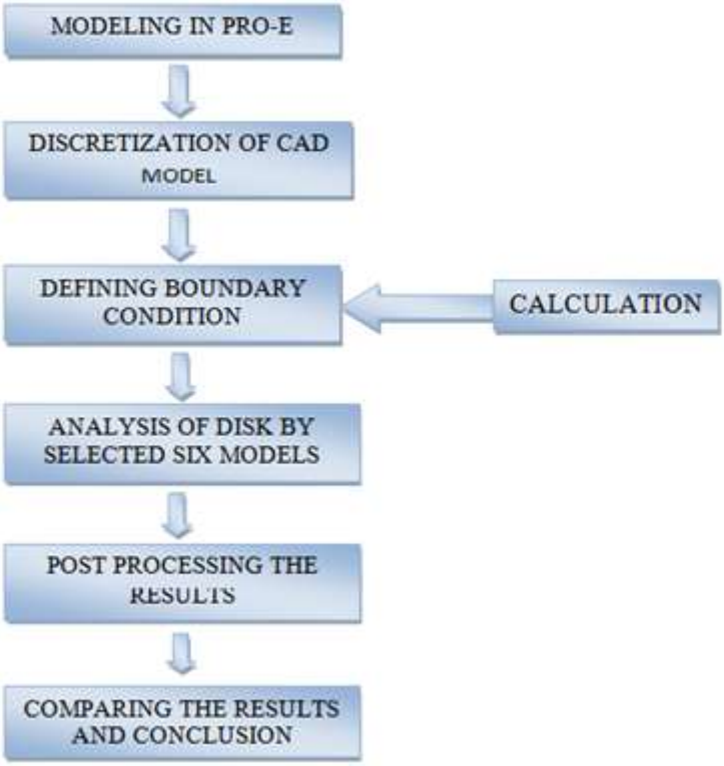
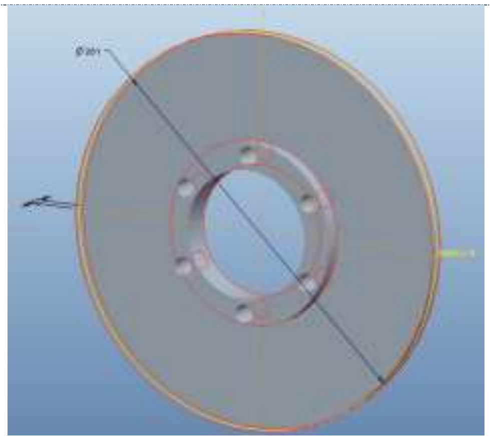


Input Parameter for Disc Plate

In this Study, stress & deformation analysis on rotor disc under condition. After completion of the finite element model it has to constrain and load has to be applied to the model.

Table 4.3.1: Specification

	Specification from Base Paper	Dimension Taken For Study
Rotor disc dimension Diameter (R)	381mm	381mm
Rotor disc dimension Thickness (T)	16mm	16mm
Hub dimension Thickness (T)	16mm	16mm
Rotor disc inside dimension	125mm	125mm
Hub Diameter	178mm	178mm
Holes Diameter	18mm (6 holes)	18mm (6 holes)
Pad Area	2587mm2	2587mm2
Rotational Velocity	125.6 red/s (N = 1200 RPM)	125.6 red/s (N = 1200 RPM)
Profile Consider	Solid and Simple Drilled	Simple Drilled of Different Shape and Arrangement, Like circular , elliptical and Star
Mass of Vehicle	300 KG	300 KG
Velocity of vehicle	80 Km/hr	60 ,80 ,100,120 Km/hr



Basic Geometric Dimensions of All Disk Plates

Design calculations for disc brake rotor-

Maximum velocity of the vehicle = 60 km/hr or 16.66 m/s

- Mass of the vehicle = 300 kg.
- Maximum velocity of the vehicle = 60 km/hr or 16.66 m/s.
- Stopping Distance = 11.69 m.
- Tire Size = 23 in diameter that is 584.2 mm with 7 mm thickness
- Disc flange or thickness = 16 mm.
- 50-50 wheel bias that is equal braking force is generated in all the 4 wheels of the vehicle.

Total force generated during braking to stop the car,
F = m*a, a = deceleration during braking = v2/2s = 16.66 2 / 2 x11.69= 11.87 m/s2
F= 300 x 11.87
F= 3561 N.

Torque required stopping the vehicle,
Tr = F/4 * Rw
Tr = 3567/4 x 0.2921
Tr = 260 N-m.

As mentioned in above formulae,
Torque generated by the rotor during braking/ Reff = Ffriction
260/.1575 = 1650 N
So Ffriction = 1650 N

In Same Process, find Ffriction for different speed of the vehicle like 80 Km/hr, 100 Km/hr & 120 Km/hr.

TABLE FOR Ffriction FOR DIFFERENT SPEED OF THE VEHICLE

Mass of vehicle	Effective Radius Taken	Velocity of vehicle	Torque Generated	Ffriction
300 Kg	0.1575 m	60 Km/hr = 16.66 m/s	260.04 N-m	1650.33 N
		80 Km/hr = 22.22 m/s	462.46 N-m	2936.25 N
		100 Km/hr = 27.77 m/s	708.48 N-m	4498.28 N
		120 Km/hr = 33.33 m/s	1040 N-m	6603.17 N

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Kinetic Energy developed during braking,
KE = ½ mv2
KE = ½ x 300 x (16.66)2
KE = 41633.34J

Total Braking Energy/Heat required for the vehicle is equal to the total Kinetic Energy generated by the vehicle,
Thus Heat (Q) generated,
Qg = 41633.34 J
Since assumption of 50-50 wheel bias is made, this heat will be equally distributed in the 4 wheels of the car, thus equally distributed in the 4 rotors. So, heat generated in 1 rotor, Qg = 10408.25
Now, the stopping time of the vehicle will be velocity/deceleration,
t = v/a
t = 16.66/21.12
t = 0.788 sec.
Hence, power generated in one rotor

P = Qg/t
P = 10408.25/1.05
P = 13208.43 Watts.
Thereby, we can calculate the heat flux through one disc rotor with 0.381m outer diameter and 0.125m inner diameter. Heat flux = 4 * P/3.14 * (Do2-Di2)
Heat flux = 4 x 13208.43/3.14 x (0.3812 – 0.1252)
Heat flux = 129890.36 Watts/m2.

Table For Heat Flux For Different Speed Of The Vehicle

Mass of vehicle	Velocity of vehicle	Kinetic Energy	Heat Flux Watts/m2
300 Kg	60 Km/hr = 16.66 m/s	10408 J	129890
	80 Km/hr = 22.22 m/s	74059 J	173408
	100 Km/hr = 27.77 m/s	115675 J	216433
	120 Km/hr = 33.33 m/s	166633 J	259597

Calculations for heat transfer coefficient

We consider warping temperature of Gray Cast Iron to calculate the film temperature, assuming the ambient or surrounding temperature to be 300 K. Warping temperatures is the temperature at Which deformation just begins and it is generally numerically equal to 70% of the melting temperature of the metal.

Tmelt for gray cast iron = 1538°C.
Twarp for gray cast iron = 70% (1538)
Twarp for gray cast iron = 1077°C. = 1350 K
Ambient temperature = Tamb = 300 K.
Film temperature = (Twarp + Tamb)/2
Film temperature = 825 K

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Thus, for the required calculations for the heat transfer coefficient at the film temperature, the air properties at this film temperature, 825 K or approx. 552°C.

Relative velocity of air (v) = 22.22 m/s
Diameter of the rotor = 0.381 m
Reynold's Number, Re = p*v*d/u
Re = (22.22 x 0.430 x 0.381)/(37.66 x 10-6)
Re = 96662.31

Nusselt Number, Nu = 0.0266 (Re)0.805 x (Pr)0.333
Nu = 0.0266 (96662.31)0.805 x (0.693)0.333
Nu = 242.65
Forced Convective Heat Transfer Coefficient, h,
h = (Nu*k)/d
h = 242.65 x 0.059835/0.381
h = 38.11 Watts/m2-K

Boundary condition for structure analysis

Structural Analysis

Velocity of vehicle	Ffriction
60 Km/hr = 16.66 m/s	1650.33 N
80 Km/hr = 22.22 m/s	2936.25 N
100 Km/hr = 27.77 m/s	4498.28 N
120 Km/hr = 33.33 m/s	6603.17 N

Structural analysis is performed for deformation, displacement, stress and strain, the boundary conditions of force and rotational velocity is applied.

Rotational velocity is w = 2.895 rad/sec.
Fixed supports are given to the hub bolts.

Solving the model: Once the conditions are applied, the model is solved for three factors:

1. Total deformation
2. Equivalent stress

Steady State Thermal Analysis
After Formulation of the heat flux thermal boundary condition they are applied on the FE model to obtain an estimate of the temperature distribution in the disc rotor. The thermal boundary condition on the rotor is as follows.

Applying boundary conditions:

Velocity of vehicle	Heat Flux Watts/m2
60 Km/hr = 16.66 m/s	129890
80 Km/hr = 22.22 m/s	173408
100 Km/hr = 27.77 m/s	216433
120 Km/hr = 33.33 m/s	259597

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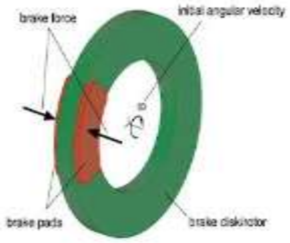
Film convective heat transfer coefficient (W/m 2-K) - 38.11

Radiation (K) - 22-27oC

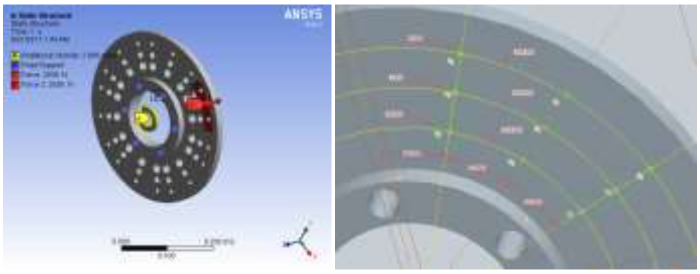
Solving the model: Once the conditions are applied, the model is solved for two factors:

1. Temperature range
2. Total heat flux



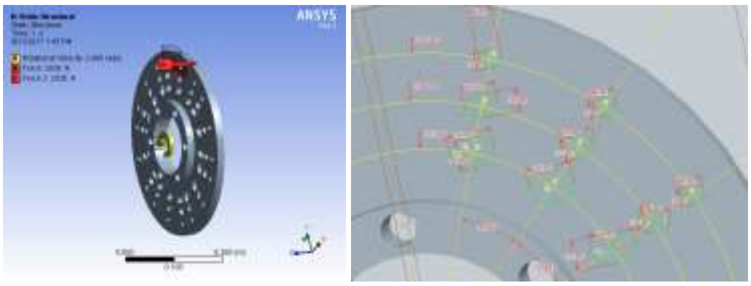
MODEL 1
Modeling of Modified disc brake rotor 1 done in Pro-E

In this model Circular holes, radius is 10, 7.5, 5 are provided straight & Decreasing Order from inner to outer & Angle 22.5º.



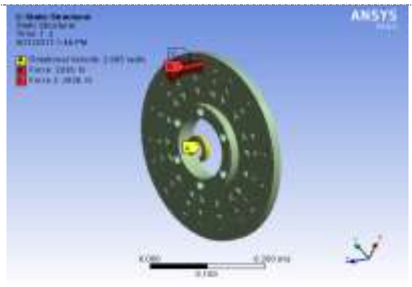
MODEL 2
Modeling of Modified disc brake rotor 2 done in Pro-E

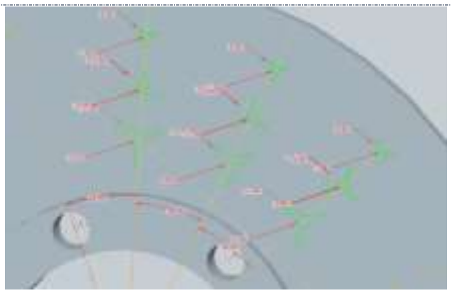
In this model Elliptical holes are provided as same surface area of the circle, straight & Decreasing Order from inner to outer & Angle 22.5º.



MODEL 3
Modeling of Modified disc brake rotor 3 done in Pro-E

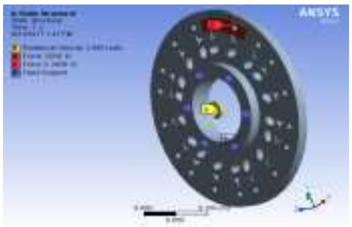
In this model 3 Star shape are provided as same surface area of the circle, straight & Decreasing Order from inner to outer & Angle 22.5º.





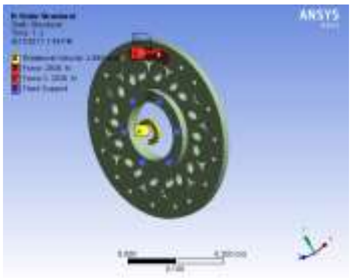
MODEL 4
Modeling of Modified disc brake rotor 4 done in Pro-E

In this model Combination of Circular, elliptical & Star Shape are provided for the removal of air & heat dissipation which can be entrapped during the braking.



MODEL 5
Modeling of Modified disc brake rotor 5 done in Pro-E

In this model Combination & diagonally of Circular, elliptical & Star Shape are provided for the removal of air & heat dissipation which can be entrapped during the braking.



Static Structure Analysis Results

Speed of the vehicle is 80 Km/hr.

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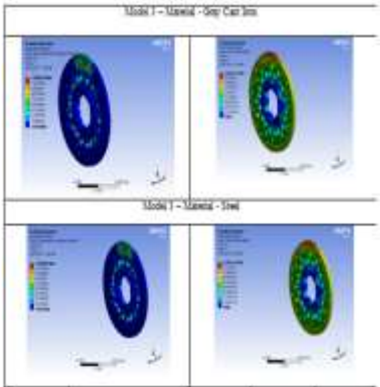
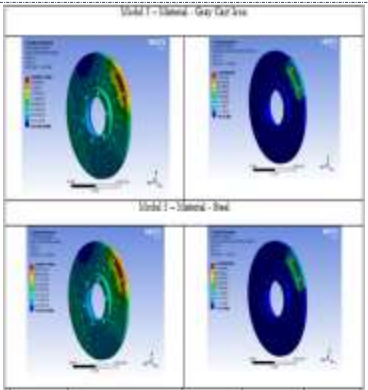
Model 1 – Material - Gray Cast Iron

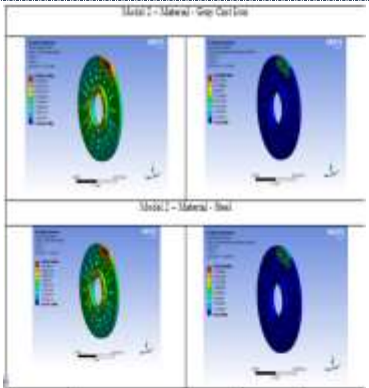
Model 1 – Material - Steel



Disc Type	Material		Stress (M pa)	Deformation (mm)	
	Gary Cast Iron		1.5887×10^{8}	2.5523×10^{-7}	
Model 1	SS		1.2808×10^{8}	1.4876×10^{-7}	



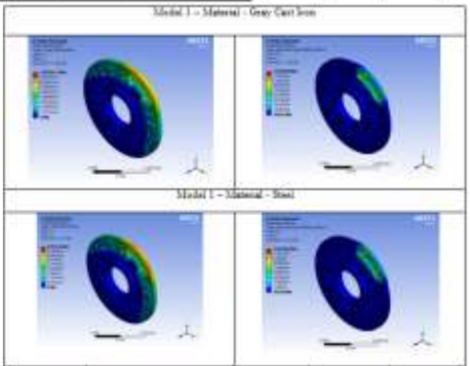
Disc Type	Material		Stress (M pa)	Deformation (mm)	
	Gary Cast Iron		1.2580×10^{8}	1.6296×10^{-7}	
Model 1	SS		1.2229×10^{8}	1.8651×10^{-7}	



Disc Type	Material		Stress (M pa)	Deformation (mm)	
	Gary Cast Iron		1.3818×10^{8}	5.5878×10^{-8}	
Model 1	SS		1.3847 × 108	5.3626×10^{-8}	

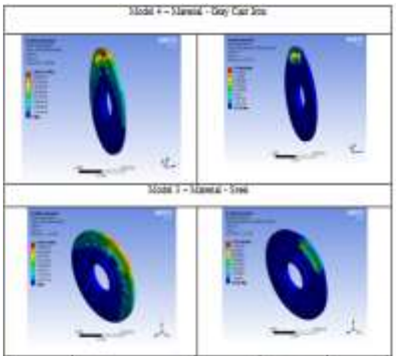
Model 1 – Material - Gray Cast Iron

Model 1 – Material - Steel



Disc Type	Material		Stress (pa)	Deformation (m)	
	Gary Cast Iron		1.3539×10^{8}	1.8555×10^{-7}	
Model 1	Steel		1.347 × 108	5.863×10^{-8}	

Model 4 – Material - Gray Cast Iron



Disc Type	Material		Stress (M pa)	Deformation (mm)	
	Gary Cast Iron		$1.3798 \times 10_{8}$	1.0511×10^{-7}	
Model 1	SS		1.3718×10^{8}	1.6459×10^{-8}	

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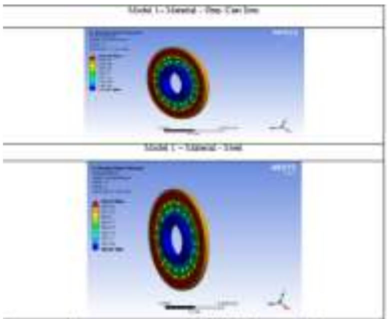
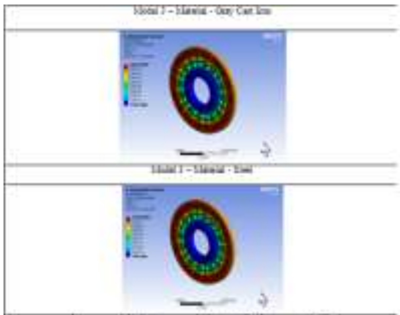
Thermal Analysis Result- Model 1

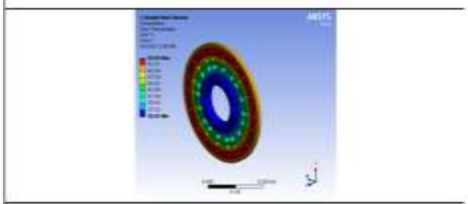


Disc Type	Material		Temperature (℃)	ΔC
	Gary Cast Iron		[illegible]	[illegible]
Model 1	SS		[illegible]	[illegible]

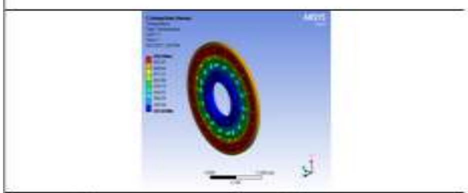


Disc Type	Material		Temperature (℃)	ΔC
	Gary Cast Iron		[illegible]	[illegible]
Model 1	SS		[illegible]	[illegible]

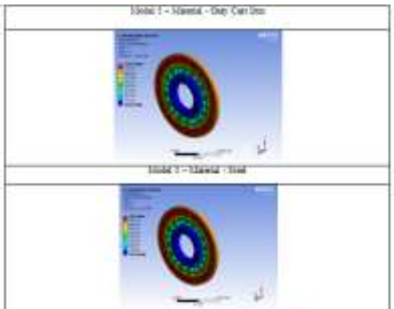
Model 4 – Material - Gray Cast Iron



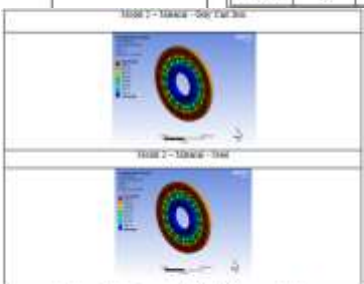
Model 4 – Material - Steel



Disc Type	Material		Temperature (℃)	ΔC
	Gary Cast Iron		352-533	181
Model 1	SS		361-525	164



Disc Type	Material		Temperature (℃)	ΔC
	Gary Cast Iron		[illegible]	[illegible]
Model 1	SS		[illegible]	[illegible]



Disc Type	Material		Temperature (℃)	ΔC
	Gary Cast Iron		[illegible]	[illegible]
Model 1	SS		[illegible]	[illegible]

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III. RESULTS AND DISCUSSION

The model was modeled by using Pro-E and in the format of IGES which is a readable format of analysis software. By observing that if speed of the vehicle is 80 Km/hr, the Structural analysis and Thermal analysis results using Gary Cast Iron and Steel the stress values are within the Safe stress value for Model Shape Disk No 3 & Safe in thermal analysis is Model Shape Disk No 5. (The greater the temperature difference, the greater the rate at which heat transfers/Cooling Effect.).

Data for Different Speed of Vehicle.

	Gary Cast Iron		Steel	
Disk No.	Stress (MPa)	Deformation (M)	Stress (MPa)	Deformation (M)
Disk 1	7.6102×10^{5}	5.9614×10^{-8}	7.6102×10^{5}	5.9614×10^{-8}
Disk 2	7.8209×10^{5}	6.1085×10^{-8}	7.8209×10^{6}	6.1085×10^{-8}
Disk 3	6.9558×10^{5}	5.8163×10^{-8}	6.9558×10^{5}	5.8163×10^{-8}
Disk 4	7.7545×10^{5}	5.9387×10^{-8}	7.7545×10^{5}	5.9387×10^{-8}
Disk 5	8.131×10^{5}	2.1294×10^{-7}	8.131×10^{5}	2.1294×10^{-7}

	Gary Cast Iron		Steel	
Disk No.	Stress (MPa)	Deformation (M)	Stress (MPa)	Deformation (M)
Disk 1	2.074×10^{6}	1.6134×10^{-7}	2.074×10^{6}	1.6134×10^{-7}
Disk 2	2.1315×10^{6}	1.6529×10^{-7}	2.1315×10^{6}	1.6529×10^{-7}
Disk 3	1.8956×10^{6}	1.5731×10^{-7}	1.8956×10^{6}	1.5731×10^{-7}
Disk 4	2.1133×10^{6}	1.6065×10^{-7}	2.1133×10^{6}	1.6065×10^{-7}
Disk 5	2.0883×10^{6}	3.0976×10^{-7}	2.0883×10^{6}	3.0976×10^{-7}

	Gary Cast Iron		Steel	
Disk No.	Stress (MPa)	Deformation (M)	Stress (MPa)	Deformation (M)
Disk 1	2.074×10^{6}	1.6134×10^{-7}	2.074×10^{6}	1.6134×10^{-7}
Disk 2	2.1315×10^{6}	1.6529×10^{-7}	2.1315×10^{6}	1.6529×10^{-7}
Disk 3	1.8956×10^{6}	1.5731×10^{-7}	1.8956×10^{6}	1.5731×10^{-7}
Disk 4	2.1133×10^{6}	1.6065×10^{-7}	2.1133×10^{6}	1.6065×10^{-7}
Disk 5	2.0883×10^{6}	3.0976×10^{-7}	2.0883×10^{6}	3.0976×10^{-7}

	Gary Cast Iron		Steel	
Disk No.	Stress (MPa)	Deformation (M)	Stress (MPa)	Deformation (M)
Disk 1	3.044×10^{6}	2.365×10^{-7}	3.044×10^{6}	2.365×10^{-7}
Disk 2	3.1288×10^{6}	2.431×10^{-7}	3.1288×10^{6}	2.431×10^{-7}
Disk 3	2.7826×10^{6}	2.3059×10^{-7}	2.7826×10^{6}	2.3059×10^{-7}
Disk 4	3.1022×10^{6}	2.3549×10^{-7}	3.1022×10^{6}	2.3549×10^{-7}
Disk 5	3.0314×10^{6}	3.8433×10^{-7}	3.0314×10^{6}	3.8433×10^{-7}

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Disk No.	Gary Cast Iron		Steel	
	Temperature (°C) Range	▲t°c	Temperature (°C) Range	▲t°c
Disk 1	297-149	148	290-157	133
Disk 2	296-148	148	289-156	133
Disk 3	463-321	142	456-330	126
Disk 4	461-314	147	455-323	132
Disk 5	469-312	148	462-321	141

Disk No.	Gary Cast Iron		Steel	
	Temperature (°C) Range	▲t°c	Temperature (°C) Range	▲t°c
Disk 1	429-201	228	419-213	206
Disk 2	428-200	228	418-212	206
Disk 3	584-373	211	574-384	190
Disk 4	582-364	218	572-376	196
Disk 5	592-362	230	582-373	209

IV. CONCLUSION

In order to improve the Strength and provide greater stability of the disc rotor in the design stage, an investigation is carried out for implementing new types/ Models of Disc Rotor.

1) In our present Study, taken Different profile shape of the disc rotor & find out that 3 star shape on the disc rotor gives better results comparison to others.
2) It also concludes that 3 Star shapes gives minimum stress in disc rotor for the two materials gray cast iron & Steel.
3) Thermal analysis is performed on different profile shapes on disc rotor & find out that if provide all three of shape if diagonally arrange (disc 5) than disc rotor is gives the best Heat Dissipation Effect. (The greater the temperature difference, the greater the rate at which heat transfers/Cooling Effect.)

From the simulation analysis of the circular, elliptical & Star shape on Disc rotor & comparing the different results, it is concluded that For Gary Cast Iron & Steel, mini Von Mises stress obtained from Modified Shape 3 disc brake rotor & high heat dissipation rate in thermal analysis is Model Shape Disk No 5. (The greater the temperature difference, the greater the rate at which heat transfers/Cooling Effect.)

So modified Shape 3 is gives better results for other modified disc. So Apply Star Shape Profile in Disk Plate for Mini Von Mises stress & modified Shape 5 is for high Heat Dissipation Effect. (The greater the temperature difference, the greater the rate at which heat transfers/Cooling Effect.)

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