Structural and Thermal Analysis with Heat Flux and Temperature Distribution on Ventilated Brake Disc

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Abstract— This study is more likely concern of structural and thermal analysis with heat flux and temperature distribution on ventilated brake disc. Structural analysis is performed to investigate the brake disc against calculated brake torque, heat flux and temperature. Thermal analysis is performed to investigate the brake disc against temperature rise and heat flux. This project also includes design optimization of ventilated brake disc with fin pattern design for better heat dissipation along with material optimization. In this study, structural and thermal analysis is performed in ANSYS 14.5 workbench. Results for structural analysis are compared with analytical method for safe design and calculated temperature is compared with actual experimental work.

Keywords: Disc brake, brake torque, Heat Flux and Temperature Distribution

I. Introduction

Disc type brake development and its use began in England in the 1890s. Disc brakes were patented by Frederick William Lanchester in 1902 but the commercial use of these brakes started in the early 1950s [1]. The brake disc is the rotating part of a wheel's disc brake assembly, against which the brake pads are applied. The design of the discs varies somewhat. Some are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces the weight and power of the vehicle determines the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily loaded front discs. Discs have holes or slots cut through the disc for better heat dissipation, to aid surface-water dispersal, to reduce noise, to reduce mass.

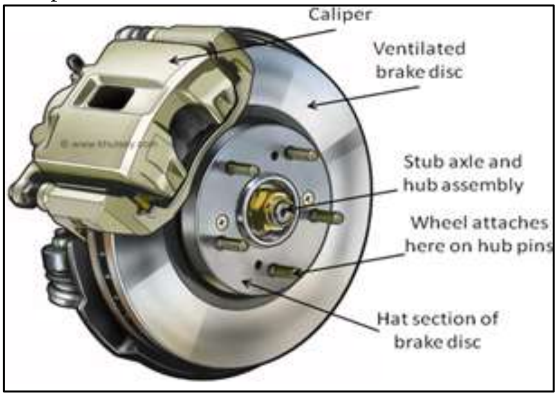

Fig. 1: Disc brake assembly

II. Problem Statement

The original brake disc on front axle that has been used previously is modified for some functional requirements. The material used previously was EN-GJL-200. The modification is done for medium capacity of commercial vehicle having gross vehicle weight as 9.6T. Due to the modification the dimension and the profile of the brake disc has changed. And material optimization is the main concern for this commercial vehicle application. As the brake disc is modified, it is necessary to check that its function properly under given load conditions. Similarly other materials have to be analyses for functional requirements.

III. Vehicle Parameters & Dimensions

The vehicle parameters are required to calculate the braking terms like braking torque, heat flux and temperature rise. The effects on these braking terms are analyzed in this project

Sr. No.	Parameters	Values	units
1	Gross vehicle weight	9.6	ton
2	Maximum speed	100	km/h
3	Wheel base	5.22	m
4	Tire specification	215/75R 17.5	
5	Tire dynamic radius	0.445	m
6	Centre of gravity height	1.2	m
7	Distance of CG from front axle	2.45	m
8	Distance of CG from rear axle	2.77	m

Table 1:

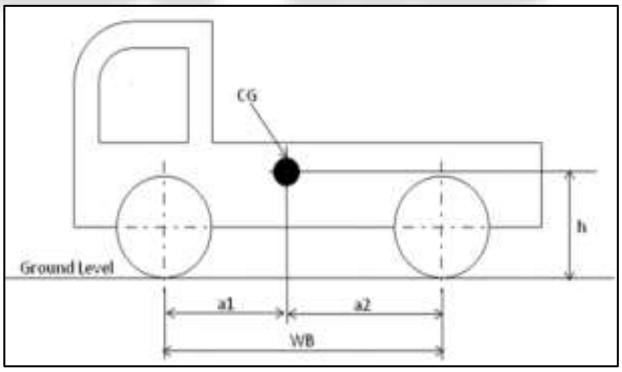

Fig. 2: Vehicle dimensions.

IV. Brake Torque Calculation

For brake torque calculation following methodology is implemented.

- Static load distribution.
- Mean fully developed deceleration (MFDD).
- Dynamic load distribution after braking.
- Total load while braking.
- Brake force on front axle.
- Brake torque acting on front axle: 1320kg.m

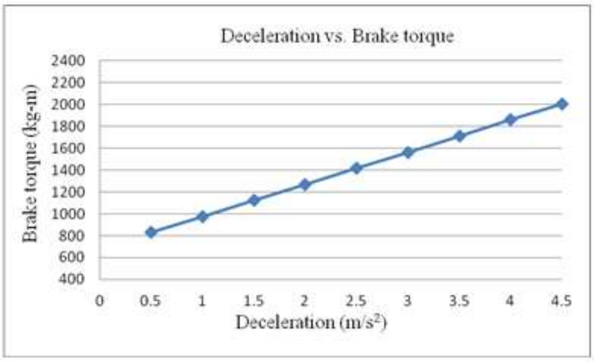

Fig. 3: Deceleration vs. brake torque relation

V. TEMPERATURE RISE & HEAT FLUX CALCULATION

- Kinetic energy
- Rotational Energy
- Total Energy
- Disc usable area
- Braking power and highest braking power
- Power distributed per disc:302728 watt
- Heat Flux: 2684665 Watts/m^2

Material	ρ (kg/m^3)	C_p (J/kg K)	K W/m-k	T ˚K
AISI-4140	7625	420	46	292
EN-GJL-200 (GG20HC)	7150	540	42	279
FG220-MoCr	7800	480	43	280
FG260Cr	7600	435	40	308

Table 2: Single stop temperature rise

A. *Temperature Rise Based on Total Energy*

When the vehicle is decelerating, the total energy is converted into heat energy. That heat energy must be transferred to atmosphere. Equating this heat energy to total energy and can be expressed with the help of equation 18[19].

$$TE = m\,Cp\,\Delta t$$

Temperature rise based on equation 18 is tabulated in the table 3.6 for various materials. Final temperature of disc is calculated by adding ambient temperature

Material	TOTAL J	ρ (kg/m^3)	m (kg)	Cp (J/kg k)	T ˚K
AISI-4140	3814815	7625	15.75	420	577
EN-GJL-200 (GG20HC)		7150	14.77	540	480
FG220-MoCr		7800	16.11	480	494
FG260Cr		7600	15.71	435	560

Table 3: Temperature rise based on equation

VI. RESULTS OF STRUCTURAL ANALYSIS

Disc is to be analyzed for structural, thermal analysis for their design optimization.

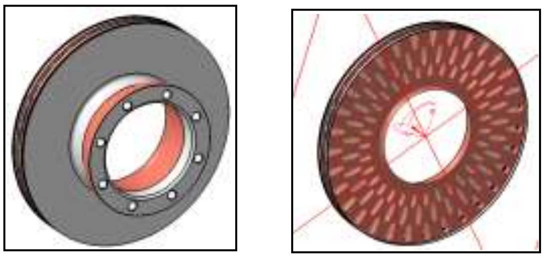

Fig. 4: Discs modeled for analysis (3D-CAD)

Structural analysis of brake disc is carried out for four different materials. For each disc maximum principle, middle principle and minimum principle stress are calculated in ANSYS and the results of each brake disc are discussed.

A. *Results for AISI-4140 (High tensile steel)*

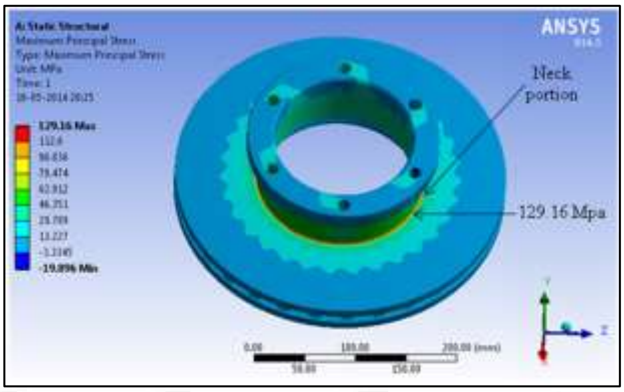

Fig. 5: Maximum principle stress (σ_1)

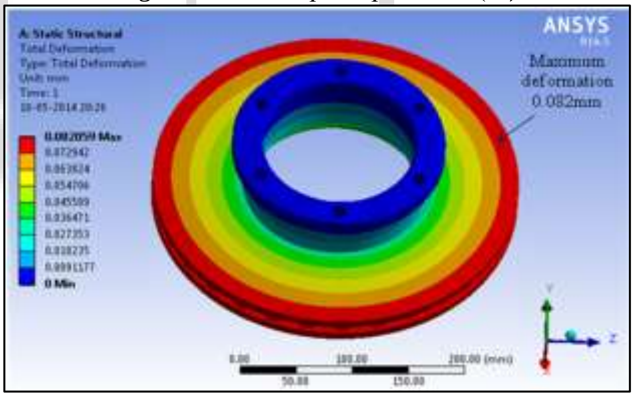

Fig. 6: Total deformation

B. *Results for EN-GJL-200 (GG200HC)*

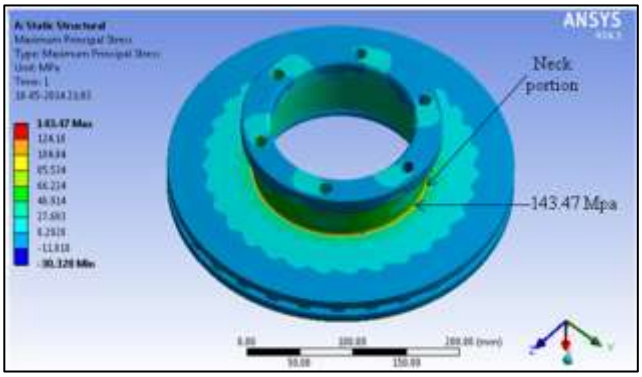

Fig. 7: Maximum principle stress (σ_1)

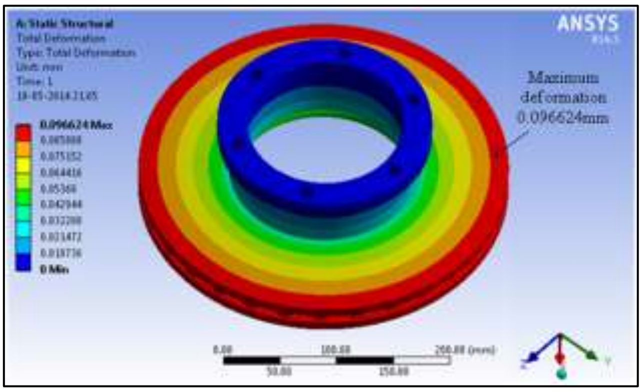

Fig. 8: Total deformation

C. *Results for FG220MoCr*

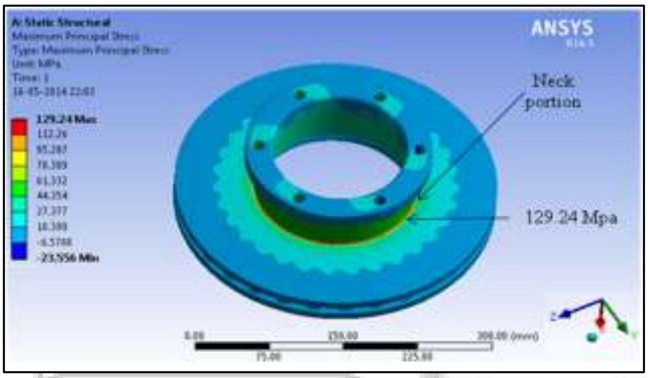

Fig. 9: Maximum principle stress (σ_1)

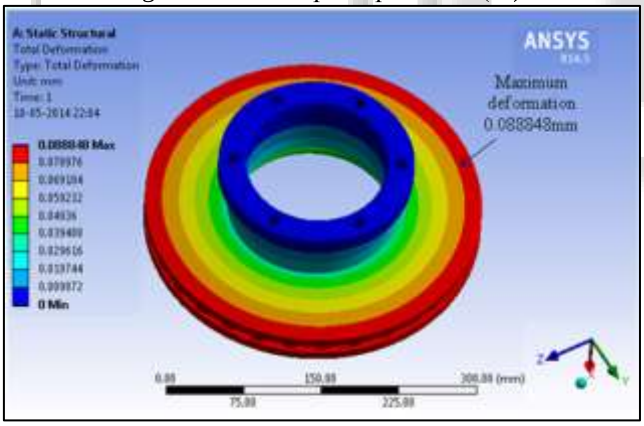

Fig. 10: Total deformation

D. *Results for FG260Cr*

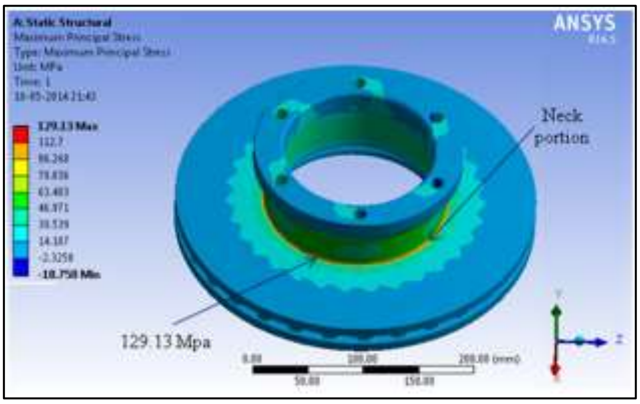

Fig. 11: Maximum principle stress (σ_1)

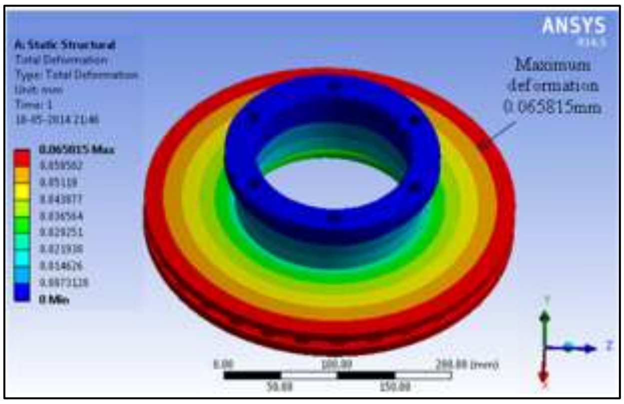

Fig. 12: Total deformation

VII. Results of Thermal Analysis

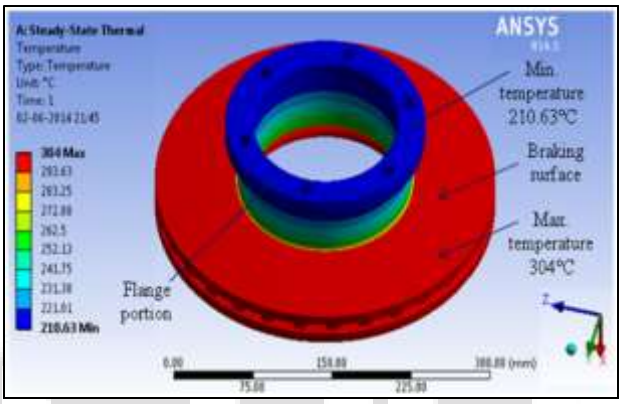

Fig. 13: Temperature distribution plot AISI-4140

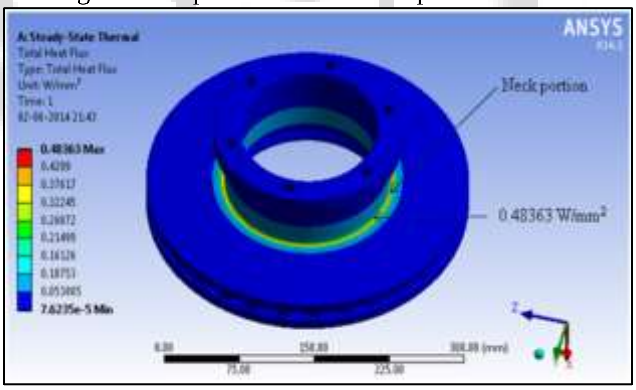

Fig. 14: Heat flux analysis AISI-4140

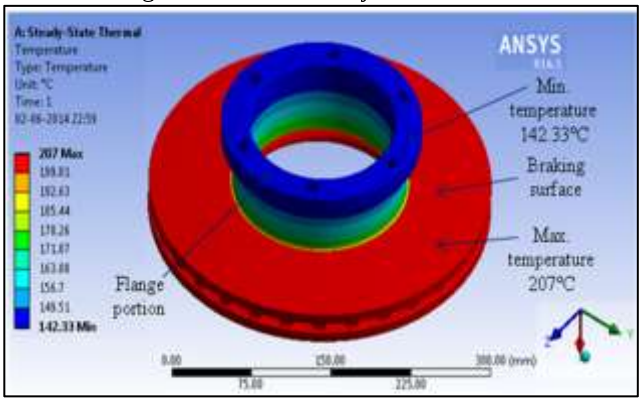

Fig. 15: Temperature distribution plot EN-GJL-200

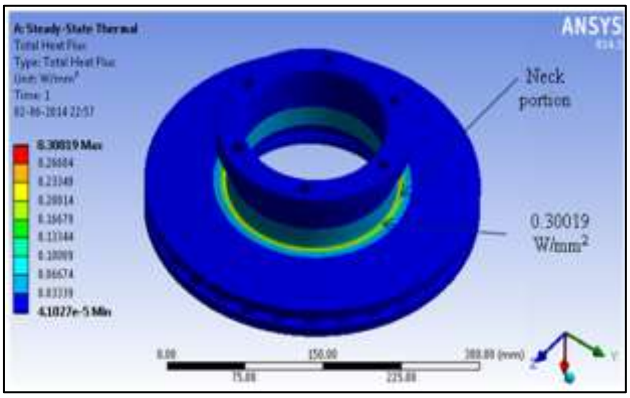

Fig. 16: Heat flux analysis EN-GJL-200

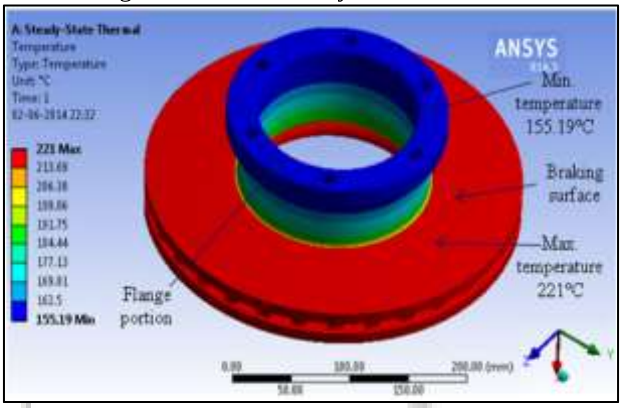

Fig. 17: Temperature distribution plot FG220MoCr

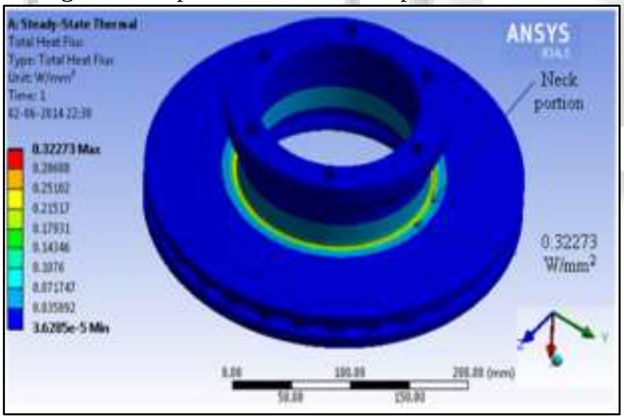

Fig. 18: Heat flux analysis FG220MoCr

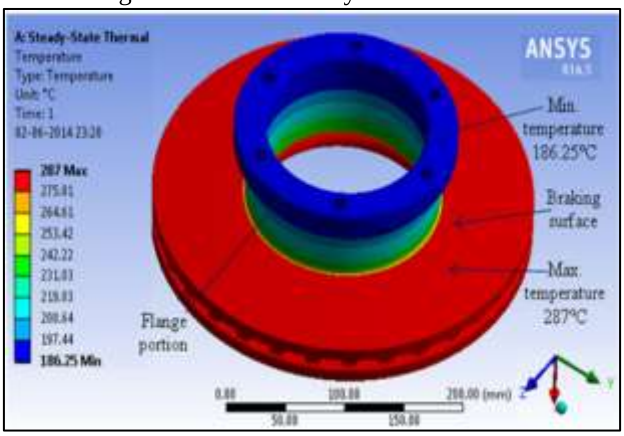

Fig. 19: Temperature distribution plot FG260Cr

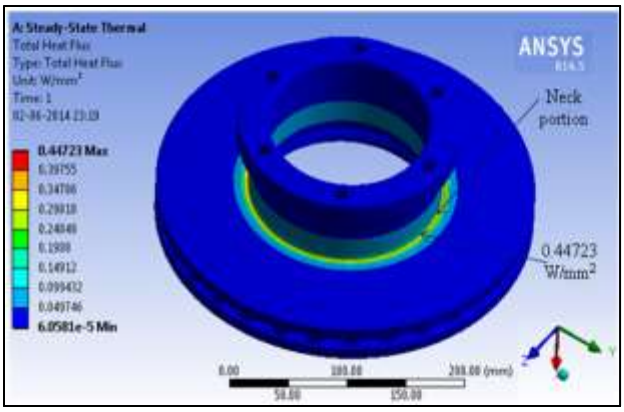

Fig. 20: Heat flux analysis FG220MoCr

VIII. SCREENING OF MATERIAL

Traditional material for automotive brake disc is the cast iron. Following table shows the chemical composition of material those which are previously analyzed can be used for brake rotor application. Out of that one optimum material can be chosen based on minimum total deformation and factor safety

Cast irons are indicated to produce brake discs because besides the low costs of the production, they have excellent thermal conductivity, which eases the dissipation of the heat generated by the friction of the pads during a stop, and the capacity of damping vibrations, which are prime characteristics of this kind of component. One of the ways to improve the heat transfer ability is to increase its thermal diffusivity. It describes the heat diffusivity during the transient process, and is also a fundamental parameter to the brake design. Brake discs with improved thermal conductivity present increase in thermal fatigue strength making it possible to increase its service life, that is, if the gray cast iron characteristic of conducting heat can be increased without sacrificing other objective criteria, the disc performance can be improved. The cast iron heat conductivity is proportional to the ratio between its surface area and its respective volume.

Material		AISI-4140	EN-GJL-200 (GG20HC)	FG220MoCr	FG260Cr
Type		Cr-Mo based high tensile steel	Coarse pearlite lamellar cast iron	Standard flake cast iron	Cr based cast iron
Chemical composition (%)	C	0.38 - 0 .43	3.40 - 3.60	3.0 - 4.0	3.10 - 3.40
	Si	0.15 - 0.04	2.30 - 2.60	0.5 - 2.0	1.60 - 2.10
	Mn	0.75 - 1.0	0.60 - 0.90	< 1	0.60 - 0.90
	P	0.04 max	0.20 max	-	0.12 max
	S	0.015 max	0.06 - 0.15	-	0.10 max
	Ni	-	-	< 1	-
	Cr	0.8 - 1.10	-	< 1	-
	Mo	0.15 - 0.25	-	< 0.5	-

Table 4:

The hardening effect produced by alloy elements in solid solution in ferrite can be seen schematically in table 7.2. Notice that despite all elements increase the alloy strength, the ones that form interstitial solid solution have a stronger effect than the substitution alones. Besides the direct way, by forming a solid solution and second-phase precipitates, alloy elements can indirectly act upon the increase in strength through grain refining, de-sulfuring or globulizing sulphides, stabilizing carbides, degasifying and also increasing the material harden ability.

Elements	C	P	Si	Ti	Al	Cu	Mn	Mo	V	Ni	Cr
Hardening effect											

PARAMETERS \ MATERIAL		AISI-4140	EN-GJL-200 (GG20HC)	FG220MoCr	FG260Cr
Principle stress (Mpa)	Maximum (σ1)	129.16	143.47	129.24	129.13
	Middle (σ2)	24.136	36.192	27.118	23.696
	Minimum (σ3)	15.148	32.788	16.988	14.895
Ultimate strength Sut (Mpa)		1020	200	220	260
Allowable stress (Mpa)		136.36	134.22	133.85	136.69
Total deformation (mm)		0.082059	0.096624	0.088848	0.065818
Factor of safety		7.5	4.5	1.7	2
Single stop temperature rise (°C) using eq. 20		69	56	57	85
Temperature rise (°C) using eq. 22		304	207	221	287

Table 5:

The Material FG260Cr is having lowest total deformation i.e. 0.065818mm for the applied brake torque 1962000N-mm as compared with other three materials. Allowable stress 136.69 Mpa which less than the ultimate strength calculated by applying “Maximum Principle Stress Theory” for brittle material. Also the calculated factor of safety is 2, which is optimum for using the brake disc material for commercial with 9.6t gross vehicle weight.

After selection of suitable material, the disc is tested on dynamometer for temperature rise. And it is found that the material FG260Cr is suitable for brake disc. The same temperature values verified with analytically as shown in figure 6.6.

IX. Conclusion

Material	Stress (Mpa)	Deformation (mm)
AISI-4140	129.16	0.082059
EN-GJL-200 (GG20HC)	143.47	0.096624
FG220MoCr	129.24	0.088848
FG260Cr	129.13	0.065818

Table 6:

Braking calculated such as:-

1) Brake force on each front wheel as 2970 kg.
2) Brake torque on each front disc 2000 kg-m i.e. 1962000 N-mm

This includes selection of material and selection of ventilation pattern for better heat dissipation. As stated earlier, four different materials were analyzed for structural and thermal analysis using ANSYS. From structural and thermal analysis it has been found that the material FG260Cr is optimum material for the brake disc as its total deformation is less as compared to other materials. As its allowable stress is less than ultimate tensile stress.

References

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