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Thermal Analysis Of Rotor Disc Of Disc Brake Of Baja Sae 2013 Car Through Finite Element Analysis

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Abstract–
This paper deals with thermal analysis through finite element analysis of rotor disc of disc brake of BAJA SAE 2013 Car. Generally brake systems are designed to apply artificial frictional resistance to the rotating member in order to stop the rotational motion of a vehicle. The rotor discs are commonly manufactured of grey cast iron[1]. The SAE also recommend grey cast iron for various applications[2]. So cast iron is being selected for analysis. The objective of thermal analysis of rotor disc is to study the temperature distribution & related thermal quantities such as thermal fluxes & thermal gradients & to evaluate the performance under severe conditions. In this present work, an attempt has been made to suggest best combination of parameters of rotor disc like Material composition, Flange Width & Wall Thickness. PRO/E wildfire 4.0 & ANSYS 13.0 software is being used for modelling & analysis of rotor disc. The Dimensions of an existing Maruti 800 car's disc rotor of disc brake are taken[3].
KEYWORDS: SAE BAJA 2013 car, Rotor Disc, Composite Materials, PRO/E Wildfire 4.0, Heat Flux, Temperature, FEA, ANSYS13.0

1. Introduction

Brakes are an energy converting mechanism that converts vehicle movement into heat while stopping the rotation of the wheels. All braking systems are designed to reduce the speed and stop a moving vehicle as desired by the driver within a minimum distance in an emergency. This is done by causing friction at the wheels. There are two basic types of friction that explain how brake systems work: kinetic, or moving, and static, or stationary. The amount of friction produced is proportional to the pressure applied between the two objects, the type of materials in contact & the smoothness of their rubbing surfaces. Friction converts the kinetic energy into heat. The greater the pressure applied to the objects, the more friction & heat produced, & the sooner the vehicle is brought to a stop[4]. The following figure is representing the types of friction acting on the vehicle during motion. Kinetic friction acts in the brakes and static friction between the tire and road to slow the vehicle.

When brakes are applied, the vehicle's weight is transferred to the front wheels and is unloaded on the rear wheels[4].

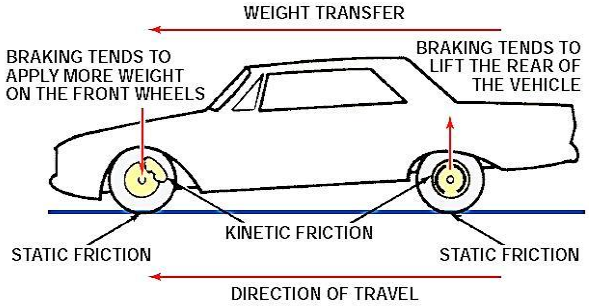

Fig1. Friction Acting On a Vehicle[4]

Fig2. CAD Model of BAJA SAE 2013 Car[4]

Fig3. SAE BAJA 2013 Car at RJIT Gwalior Campus

Fig4. Actual Disc Brake Assembly

In our BAJA SAE car we used Disc brakes because it has four major advantages over drum brakes[4]. Disc brakes are more resistant to heat fade during high-speed brake stops or repeated stops. The design of the disc brake rotor exposes more surfaces to the air and thus dissipates heat more efficiently. They are also resistant to water fade because the rotation of the rotor tends to throw off moisture.

2. Material of Rotor Disc of Disc Brake

The rotor discs are commonly manufactured of grey cast iron[1]. The SAE maintains a specification for the manufacture of grey iron for various applications[2]. It is primarily composed of Iron 95%, Carbon 2 to 5%, Silicon 1 to 3%, & also contains small percentage of Sulphur, Manganese & Phosphorus. Grey cast iron has high specific heat capacity & thermal conductivity which makes them suitable for making of rotor disc. Other properties are young's Modulus of Elasticity, Torsional Modulus of Elasticity, Crushing Strength, Brinell hardness & Endurance Limit. The material properties of grey cast iron are:

Density- 7100 kg/m3 Young modulus- 125 GPa

Poisson's ratio- 0.25 Specific heat- 586 J/Kg.K
Thermal conductivity- 54 W/m.K

Here for thermal analysis we have considered 5 rotor disc materials Grey cast iron, Aluminum metal matrix composites, E glass fiber, Ceramic & Hard rubber.

Fig5. BAJA SAE Car's Rotor Disc

3. Modeling of Rotor Disc

The rotor disc modelling is done in PRO/E 4.0 software created by Parametric Technology Corporation, USA. It is parametric, feature-based, bi-directional associative nature solid modelling software. The assumptions which are

made while modeling the process are given below[5].

- The rotor disc material is considered as homogenous and isotropic.
- The problem domain is considered as axis-symmetric.
- Inertia & body force effects are negligible during the analysis.
- No stress in rotor disc before the application of brake.
- Brakes are applied on the all 4 wheels.
- Rotor disc is of Solid type not ventilated.
- Thermal conductivity of the material used for analysis is constant.
- Only ambient air cooling is considered.
- Specific heat of rotor disc material is constant & does not change with temperature.

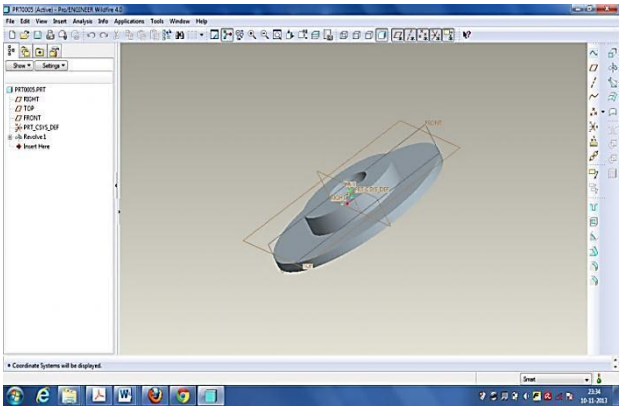

Fig6. CAD Model of Rotor Disc

4. Finite Element Analysis using ANSYS

Finite element method is a numerical method for solving any engineering problem. Because it is the mathematical representation of physical problems & it gives the approximate solution & also applicable even if physical prototype not available[6]. ANSYS is FEA software developed by ANSYS Inc. USA. ANSYS involves three stages preprocessing, solution & postprocessing for solving problems.

Preprocessing stage involves the preparation of FEM model, element type, real constant, material property & discretization.

In Solutions stage ANSYS software automatically generates matrices that describe the behaviour of each element, assemble them & computes the unknown values of primary field variables such as displacement, temperature etc.[6]

Postprocessing stage involves the presentation of results.

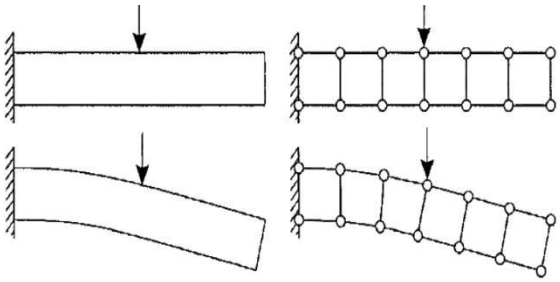

Fig7. A cantilever beam & its FEM Model[7]

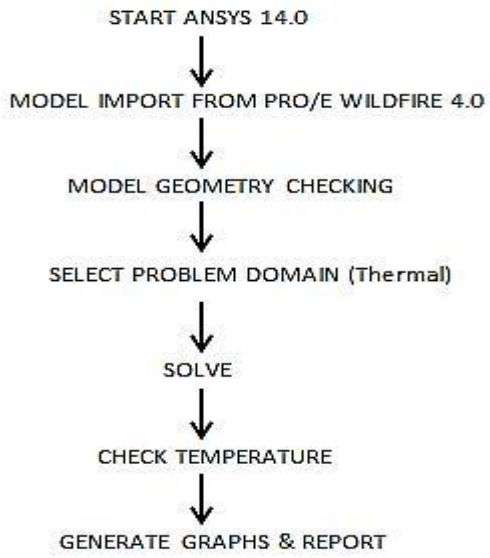

Fig8. Flow Chart (ANSYS)

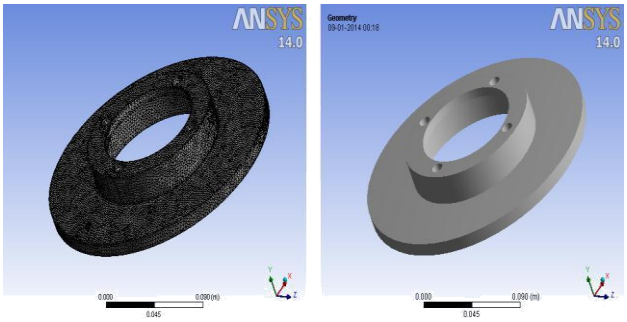

Fig9. FEM Model & Solid Model

5. Results

A steady state thermal Analysis also calculates the temperature distribution & other thermal related quantities in rotor disc under steady state loading conditions. A steady state loading condition is a situation where heat storage effects varying over a period of time can be ignored. For thermal analysis we have calculated the following values & find out Heat Flux during 4 sec of braking.

1) Input Driver Force=150N
2) Pedal Ratio 5:1
3) Pedal Effort F_p = 150*5 = 750N
4) Diameter of Master Cylinder d_m = 25.4mm
5) Area of Master Cylinder A_m= $5.16*10^{-4}m^2$
6) Brake Line Pressure P_c = 1453488.37 Pa
7) Caliper Piston Diameter d_p = 38.1mm
8) Area of Caliper A_c = $1.15*10^{-3}m^2$
9) Force on Caliper C_f = P_c*A_c *2Piston = 3343N
10) Coefficient of friction of pad μ=0.45
11) Clamping Force N = 2*μ*Force on Caliper = 2*0.45*3343N = 3008.7N
12) Effective Radius R_e = 0.08845m
13) Braking Torque available T_b = $N*R_e$ = 266.12 Nm
14) Rolling Radius of Tyre = 292.1mm
15) KE = 370 (12.5^2-0^2) = 28906.25 J or Nm
16) Total KE = Heat generated during braking = 28906.25 J
17) Area of Rubbing Surfaces = $\Pi(Do^2-Di^2)/4$ = $\Pi(.215^2 - .138^2)/4$ = $0.0214m^2$, Twice this area of rubbing surface as this will act on both side = $0.042673m^2$
18) Heat Flux = Heat Generated/Second/Rubbing Area = 261988.59 watts/m^2

The analysis is done by taking the braking torque distribution between the front & rear is 70:30

19) Heat Flux on each front wheel = 91696.01 watts/m^2
20) During 4sec of braking = 59372watts/m^2

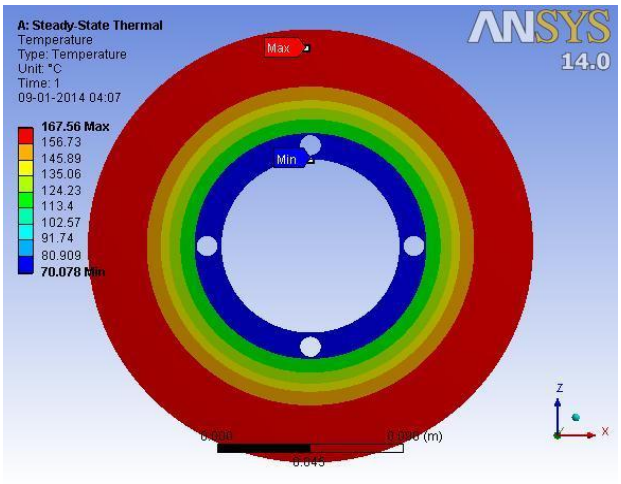

Fig10. Temperature Distribution for Grey Cast Iron Rotor Disc

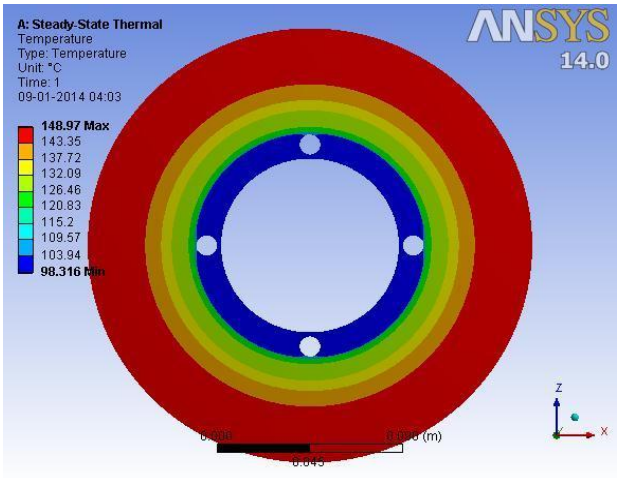

Fig11. Temperature Distribution for Al MMC Rotor Disc

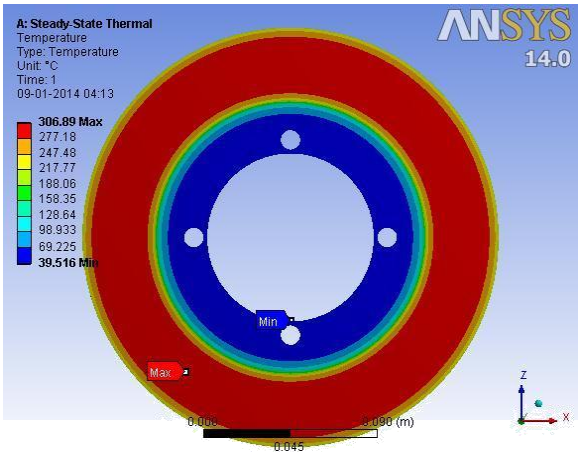

Fig12. Temperature Distribution for E Glass Rotor Disc

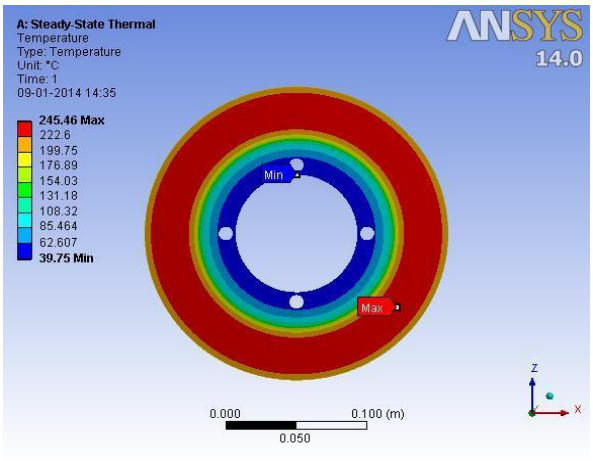

Fig13. Temperature Distribution for Ceramic Rotor Disc

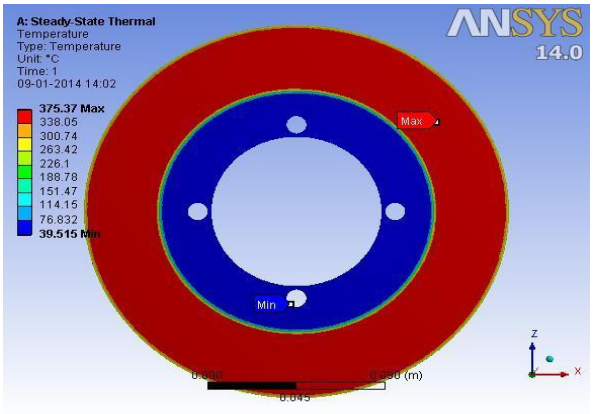

Fig14. Temperature Distribution for Hard Rubber Disc

S.No.	Material	Max. Temp. (˚C)	Min. Temp. (˚C)
1	Grey Cast Iron	167.56	70.078
2	Al MMC	148.97	98.316
3	Ceramic	245.46	39.75
4	E Glass	306.89	39.52
5	Hard Rubber	375.37	39.51

Table 5.1 Temperature Distribution & maximum stress during Braking in Various Materials

For analyzing stability & performance of rotor disc of disc brake of BAJA SAE 2013 first we collected various data related to vehicle & Calculated various parameters in normal & hard braking. After that we performed static thermal analysis in ANSYS 14.0 on rotor disc using previous calculated data for various materials as earlier discussed. For validation of results we compared FEA results with digital logic method & Fracture analysis method.

6. Conclusion

The main conclusions drawn from the program of work reported in this paper are as follows.

- Thermal analysis is carried out for the application of braking force because of friction for the time duration of 4 seconds.
- The maximum temperature obtained in grey cast iron rotor disc is at rubbing surface & is observed to be 167.56 ˚c.
- The grey cast iron rotor disc is safe based on strength & stability criteria.
- To achieve a best combination of parameters of rotor disc like size, type & materials, & thermal analysis for 5 different material combinations were done & results were validated using digital logic & fracture analysis method.

- By comparing the different results obtained from FEA & analytical analysis it is concluded that rotor disc of grey cast iron having 10mm thickness & 215mm diameter is the best suitable combination for the present application.

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