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Design and Analysis of Carbon Fiber / Epoxy Resin Brake Rotor

Goutham Kumar Reddy Challa[1], Abhinoy Krishna Guduru[2], Siddhartha Patlori[3], Dr.M.Madhavi[4]
[1,2,3](Automobile Engineering, M.V.S.R Engineering College, India)
[4](Professor and Head of the Department, Department of Mechanical Engineering , M.V.S.R Engineering College, India)

Abstract:*The paper describes the design and finite element analysis of carbon fiber-epoxy resin brake rotor. The design and finite element analysis is performed by using computer aided design (CAD) software. The objective is to design and analyze the thermal and structural stress distribution of brake rotor at the real time condition during braking process. The optimization is carried out to reduce the stress concentration and weight of the brake rotor which keeps the unsprung mass low thereby increasing the stability of the vehicle. With using computer aided design (CAD), SOLIDWORKS software the structural model of brake rotor is developed. Furthermore, the finite element analysis performed with using the software SOLIDWORKS SIMULATION AND ANSYS.*

Keywords*:Carbon Fiber, Epoxy Resin, Brake Torque, Clamping Force, Thermal Stresses.*

I. Introduction

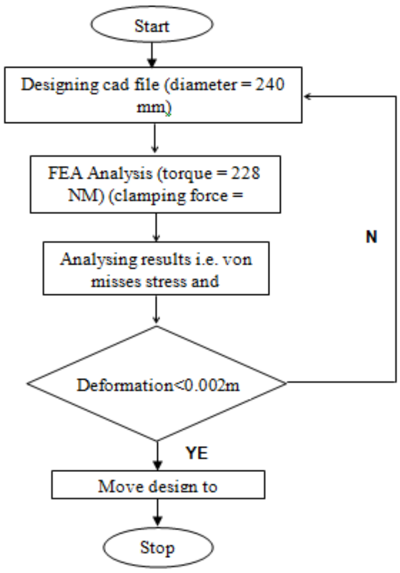
The design of new brake rotor (i.e. with new material) is parametric optimization of existing brake rotors with new properties and same old set of constraints. The main purpose of opting new material is to increase life i.e. better anti fade or anti wear characteristics, light weight(which reduces the unsprung mass and increases vehicle stability), complete corrosion resistance until component undergoes fatigue failure.

When you design a new component, the set of objectives and constraints must be met. An optimum design can be achieved based on predetermined criteria using computational methods.The material used in brake rotors should be able to bear thermal fatigue and should absorb and dissipate, as soon as possible, the heat generated during braking. The high thermal conductivity allowing lower temperatures in the region under friction, which contributes to an increase in life of the component.

Finite element techniques are used to analyze a carbon fiber-epoxy resin disc brake rotor that is lighter and performs as well as existing brake rotors. Under normal braking, the rotor should remain in its elastic region. Otherwise the rotor would deform after each use.

II. Design methodology

The first step is development of CAD model according to geometric specifications followed by selection of material. Finite element analysis is done using simulation software varying the disc thickness until the deformation is within the elastic region.



III. Material Selection

The material for brake rotor is selected such that it should meet the requirements like strength, hardness, corrosion resistance. The material should also possess some good thermal conductivity, so that the heat generated during braking is readily dissipated into atmosphere.

3.1 Carbon fiber: Carbon fiber, alternatively graphite fiber or CF, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms.
The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion.

Fig 1 Bi-Directional Carbon Fiber Sheets

3.2 Epoxy:Epoxy is the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy is also a common name for a type of strong adhesive used for sticking things together and covering surfaces, typically two resins that need to be mixed together before use. It can also be used as a solver due to its high melting and boiling points.

Property	Carbon Fiber
Elastic Modulus (N/mm^2)	70000
Poisson's ratio	0.1
Shear Modulus (N/mm^2)	5000
Mass Density (kg/m^3)	1600
Tensile Strength (N/mm^2)	600
Compressive Strength (N/mm^2)	570
Coefficient of Thermal Expansion (/K)	$0.2\ e^{-06}$
Thermal Conductivity (w/m-K)	28

Table 1Properties of carbon fiber

IV. Design calculations of brake rotor

The dimensions of Honda Shine brake rotor was considered for the design purpose
Disc diameter = 240 mm
Pad rotor contact = 60 mm (radius)
P = fluid pressure, Pa
FP = pedal force = 25 Kg =245 N
R = pedal lever ratio = 4: 1
H = Pedal efficiency = 0.8

Standard size of master cylinder is 12.055mm.
Actual Pressure generated by the system, $P = (FP*R*\eta) / A$
$= (245 \times 4 \times 0.8 \times 4) / (\pi \times 12.055^2 \times 10^{-6})$
= 6.87MPa.

4.1 Clamping Force is calculated as:

$$CF = PM \times AT$$

Where,
CF = Clamping Force (N)
PM = Maximum hydraulic pressure (Pa)
AT = Total effective area of caliper pistons (m^2) – for fixed calipers this is the actual area of the pistons, for floating calipers this is equal to 2 x the actual area of the pistons.

$$CF = (6.87 \times 10^6 \times 2\pi \times 0.02591^2)/4$$
$$= 7240.88 \text{ N}$$

4.2 Brake Torque Developed is calculated as:

$$T_{Bd} = CF\ (\mu_L)\ Re$$

Where
T_{Bd} = Brake Torque Developed (N-m)
CF=Clamping Force(N)
μ=Coefficient of friction between brake pads and rotors (= 0.3)
Re = Effective rotor radius (m) – measured from the center of the rotor to the center of the brake pad.

$$T_{Bd} = CF \times \mu \times Re$$
$$= 7240.88 \times 0.3 \times 0.105$$
$$= 228 \text{ Nm}$$

4.3 CAD Model and Analysis Results

Material: Carbon Fiber/Epoxy resin
Disc diameter = 240mm
Rotor-pad contact area = 60 mm
Disc thickness = 8mm

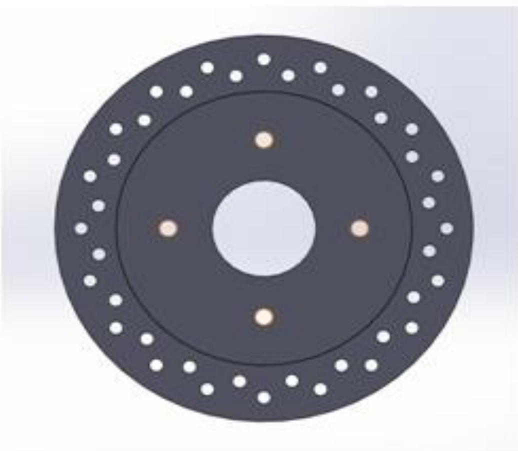


Fig 2: CAD model of 8 mm Carbon Fiber Disc

4.4 Boundary conditions for Structural analysis:
1. Fixtures – four bolt holes and nominal shaft hole
2. External loads – torque = 228 NM, Clamp
Clamping force = 3620.5 N (applied on both faces of pad-rotor contact area)

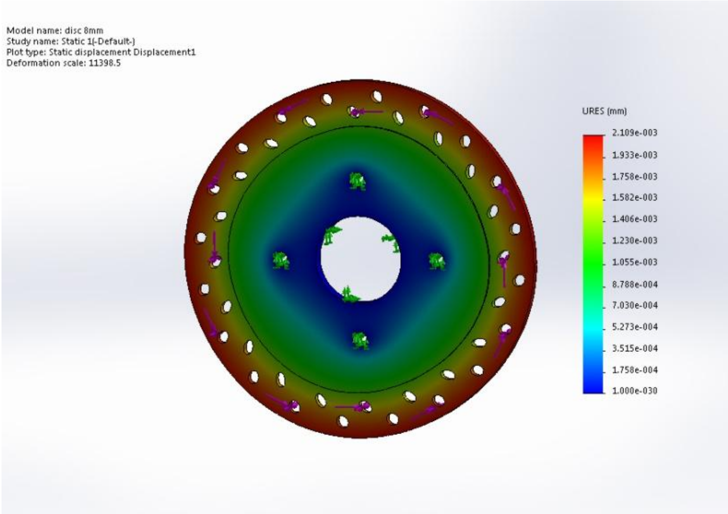


Fig 3: Displacement of 8 mm Disc

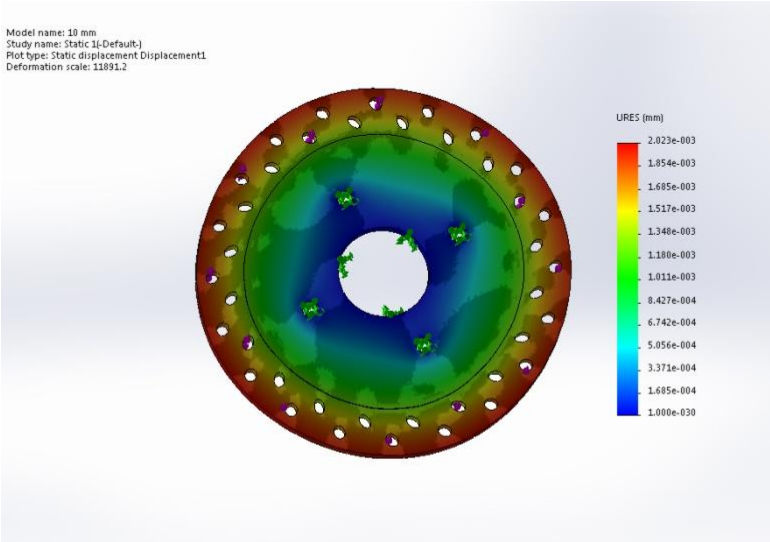


Fig 4: Displacement of 10 mm Disc

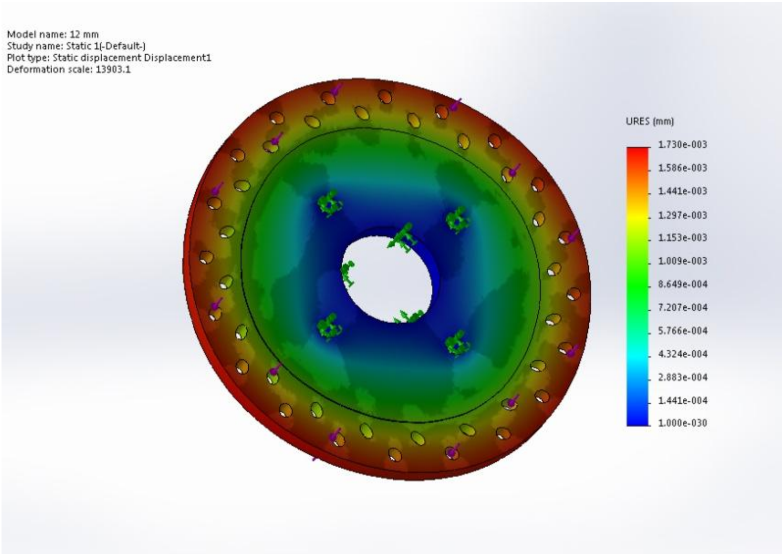


Fig 5: Displacement of 12mm Disc

Material	Deformation
Carbon Fiber (8mm thickness)	2.109 e^{-03} mm
Carbon Fiber (10mm thickness)	2.023 e^{-03} mm
Carbon Fiber (12mm thickness)	1.730 e^{-03} mm

Table 2: Comparison of deformation in various thickness

4.5 Transient -Thermal analysis:

The principle of braking is kinetic energy with which the vehicle is propelling is converted to heat energy when brakes are applied. Therefore the disc should posses high heat transfer rate to dissipate the heat produced when brake is applied. The mode of heat transfer at brakes is combination of convection and radiation. Heat produced when brake applied is dissipated into surroundings through convection between pad-rotor and air around it. Heat generated on the disc is cooled to ambient temperature through radiation.

4.6 Thermal calculations:

Kinetic energy of vehicle = ½ * m * v^2
= ½ * 200 * 33.32
=110889 J

Total heat = Kinetic Energy/ time
= 110889 / 3
= 36963

Total heat (one side) = 36963/2
=18482 W

4.7 Analysis inputs:

Heat flux = 20000 W
Ambient temperature = 25 ºc
Convection heat transfer coefficient = 140 w/m^2 k

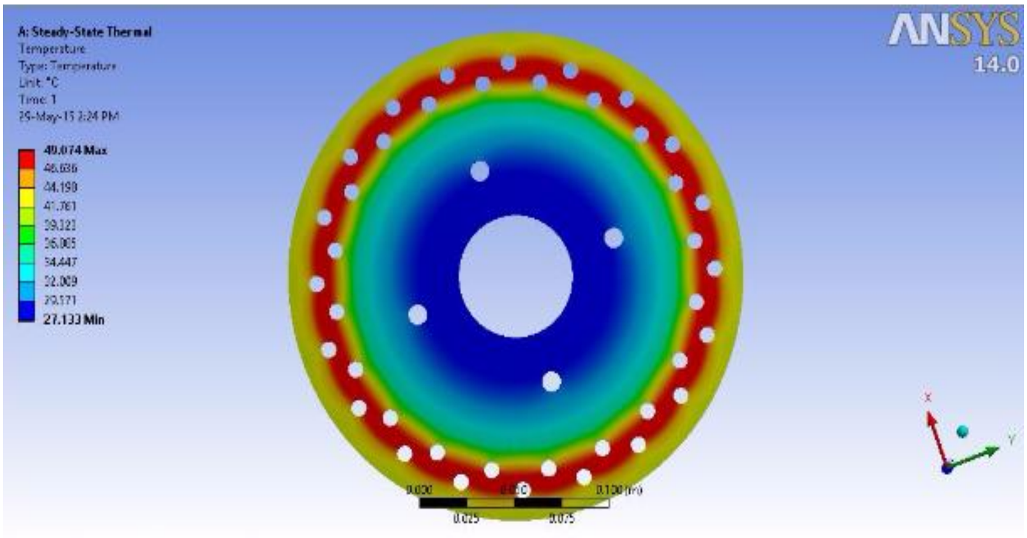


Fig 6 Thermal analysis on brake rotor

Maximum temperature = 49.074 ºc
Minimum temperature = 27.133 ºc

V. Result

The carbon fiber/epoxy resin disc with dimensions disc diameter of 240 mm and disc thickness of 12 mm has minimum deformation and stress values. The temperature change due to application of brake is also less and therefore heat dissipation takes place at faster rate and wear of the disc is also very less.

VI. Conclusion

A carbon fiber brake rotor was designed, structural and thermal analysis was performed with different thickness and a 12mm disc has very less deformation. . The most important aspect is that it was found to be 50% lighter than a conventional brake disc rotor (mass properties by computational method)

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