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Design and Thermal Analysis of Disc Brake Rotor Using Aluminum Alloy 2014 and Generalized Experimental Analysis for Temperature Distribution

D.Maneiah
Professor & HoD
Mechanical Department- Thermal
CMR Technical Campus.

Levicus John
Assistant Professor
Mechanical Department- Thermal
CMR Technical Campus.

M.Saikrishna
M.Tech Student
Mechanical Department- Thermal
CMR Technical Campus.

ABSTRACT

Disc brakes are exposed to large temperature resulting large thermal stress during routine braking. These large temperature extrusions have two possible outcomes: fade that generates reduction in stopping power; and large amount of plastic deformation that generates low fatigue life in the brake rotor. The aim of the present work is to investigate the temperature distribution of Aluminum alloy disc brake during first braking phase using analytical, as well as for mild steel in finite element (FE) method and comparing the result. The area of study is concentrated on temperature variation as a function of time only. Only the areas exposed to high temperature is selected for analysis, specifically the rotor, by excluding hub and vanes because they are for from disc-pad contact. One particular existing brake disc design for a SUV car of model mahindra is chosen for the investigation. The dimensions, material property and maximum allowable speed of this car are used as an input both for analytical and finite element method.. The finite element simulation for the coupled transient thermal field and is carried out by separate data base thermal coupled method based on NX9 to evaluate the temperature profile. The result show maximum temperature and at the surface and these affects tribological properties such as damage and failure at the surface of the disc.

INTRODUCTION

A brake disc rotor is the rotating part of a disc brake assembly normally located on the front axle which is most important safety feature of an automobile. The ability of a braking system to provide safe, repeatable stopping is the key to safe motoring. To stop the wheel, friction material in the form of brake pads (mounted in a device called a brake caliper) is forced hydraulically, against both sides of the disc. The purpose of friction brakes is to decelerate a vehicle by transforming the kinetic energy of the vehicle to heat, via friction, and dissipating that heat to the surroundings. So friction based braking systems are still the common device to convert kinetic energy into thermal energy, through friction between the brake pads and the rotor faces. Braking system is performed by combination of different components of disc brake assembly such as caliper, piston and cylinder, pads, and rotor.

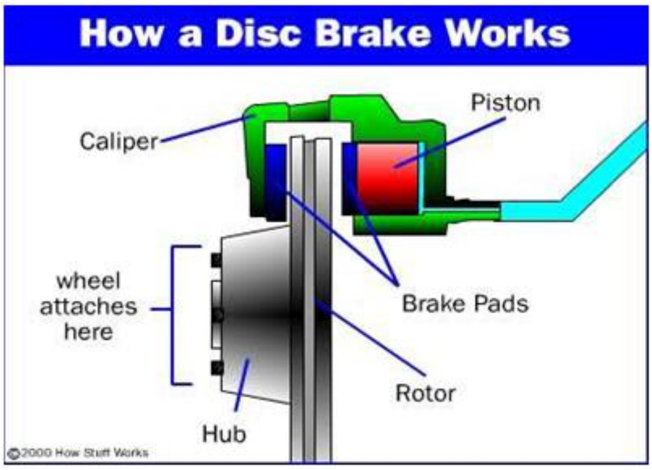

Figure 1 Disc brake parts.

Disk Brakes

A disk brake consists of a cast iron disk bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to some stationary part of the

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vehicle like the axle casing or the stub axle as is cast in two parts each part containing a piston. In between each piston and the disk there is a friction pad held in position by retaining pins, spring plates etc. passages are drilled in the caliper for the fluid to enter or leave each housing. The passages are also connected to another one for bleeding. Each cylinder contains rubber-sealing ring between the cylinder and piston.

Disk brake types:

1. Drilled type
2. Drilled and slotted.
3. Disk with internally slotted.

Figure 2 Disk of drilled type

Figure 3 Disk of slotted type

Figure 4 Disk with internally slotted

Figure 5 Brake pads

Analytical and Boundary Conditions

Assumptions

- Brake is applied on all the front wheel only.
- The analysis is based on pure thermal loading. The analysis does not determine the life of the disc brake.
- The kinetic energy of the vehicle is lost through the brake discs i.e. no heat loss between the tyres and the road surface and the deceleration is uniform.
- The disc brake model used is of homogenous material.
- The thermal conductivity of the material used for the analysis is uniform throughout.

The specific heat of the material used is constant throughout and does not change with the temperature.

Item Values:

1. Disc Diameter	: 298 mm
2. Disc Thickness	: 24 mm
3. Centre Diameter	: 98 mm
4. Diameter at base	: 190
5. Size of pad	: 114*78*16
6. Weight of Automobile	: 1330 kg
7. Top Speed of Automobile	: 130 Kmph
8. Tire Size 235/45ZR18	
9. Mass of the disc	: 5 kg
10. Time taken to stop the vehicle	: 4 secs
11. Specific heat, Cp	: 910 Jkg-1k-1

12. Axle weight distribution 30% on each side (γ)=0.3

13. Percentage of kinetic energy that disc absorbs (90%) k=0.9

14. Acceleration due to gravity g =9.81m/s2

15. R2 = Outer Radius of the pad

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16. R1 = Inner Radius of the pad
17. t = Time taken to stop the automobile
18. V= Speed of an automobile m/s.

Kinetic energy generated (KE)

$$K*0.5*MV^2*\gamma$$
$$= 0.9*0.5*1330*(31.1)^2*0.3$$
$$=173662.5\ J$$

Watt $= 43415.63W$

Heat flux = Wattage/Disc usable area

$$= 25408.47/0.0317$$
$$= 1369578.513W/m^2$$

Disc usable area $= \pi(D_2^2 - D_1^2)/4 = \pi(0.298^2 - 0.22^2)/4$

$$= 0.03173m^2$$

Calculation for Heat transfer coefficient: (h)

Properties of Air at 20°C.

Density	1.205 kg/m³
Specific Heat	1.005 kJ/kg.k
Thermal conductivity	0.0257 kw/m.k
Kinematic viscosity (v)	15.11×10^{-6} m²/s
Thermal expansion coefficient (1/T)	3.43
Prandtl number	0.713

$$Re = \frac{\rho VD}{\mu}$$

Reynolds number range	Formula
4000-40,000	Nu=0.193**
Above 400000	Nu= 0.0267**

Heat transfer coefficient for 24 mm thickness disc for analysis (h)=124 W/m².k

Heat transfer coefficient for 3mm thickness disc for generalized experimental analysis (h) =14W/m2.k

Maximum Temperature rise Tmax.

$$T_{max} = \frac{0.527*q*\sqrt{t}}{\sqrt{\rho*C*K}} + T_{amb}$$

T_{max} = maximum disc temperature

T_{amb} = ambient temperature

q = Heat flux W/m²

t = Braking time in sec

ρ = Density kg/m³

C = Specific heat of material in kJ/kg.k

K = Thermal conductivity in W/m.k

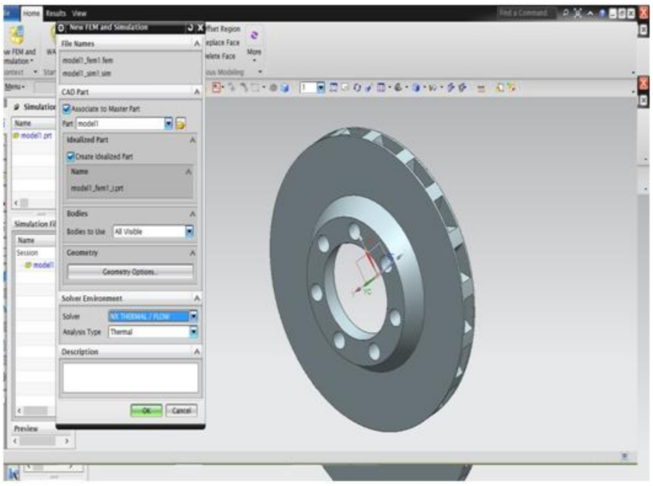

Figure 6 shows Design and modeling in NX9

Meshing of the disc

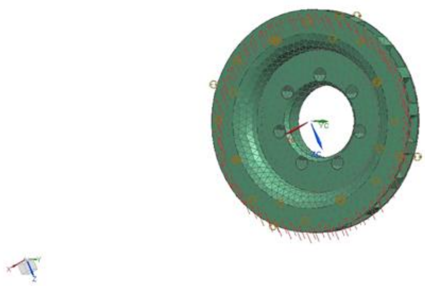

Figure 7 shows Meshing of disc

SOFTWARE USED FOR MODELING AND ANALYSIS NX9

NX is one of the world's most advanced and tightly integrated CAD/CAM/CAE product development solutions. Spanning the entire range of product development, NX delivers immense value to enterprises of all sizes. It simplifies complex product designs, thus speeding up the process of introducing products to the market. The NX software integrates knowledge-based principles, industrial design, geometric modeling, advanced analysis, graphic simulation, and concurrent engineering. The software has powerful hybrid modeling capabilities by integrating constraint-based feature modeling and explicit geometric modeling. In addition to modeling standard geometry parts, it allows the user to design complex free-form shapes such as airfoils and

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manifolds. It also merges solid and surface modeling techniques into one powerful tool set.

This self-guiding tutorial provides a step-by-step approach for users to learn NX9.0. It is intended for those with no previous experience with NX. However, users of previous versions of NX may also find this tutorial useful for them to learn the new user interfaces and functions. The user will be guided from starting a NX9.0 session to creating models and designs that have various applications. Each chapter has components explained with the help of various dialog boxes and screen images. These components are later used in the assembly modeling, machining and finite element analysis.

GENERALIZED EXPERIMENTAL ANALYSIS FOR DISK BRAKE

Apparatus

- Two discs of different materials one is made of Aluminum and other Mild Steel.
- Mild steel rod for making mandrel assembly on chuck
- Lathe for loading and kinetic energy.
- Thermometer for temperature measurement.
- Brake pads to generate heat due to friction.
- Welding tongs for loading purpose.
- M8X15 mm bolts for disc arrangement.
- M8X100mm bolts for uniform loading purpose.
- Digital thermometer for measurement.

Disc Arrangement:

- Two discs of made of Aluminum and other is mild steel of 200mm diameter and 3 mm thickness is taken for analysis.
- Centre hole is drilled on the disc of 10mm diameter.
- Again 3 holes are drilled at diameter of 50 mm which makes angle of 120o with each other.

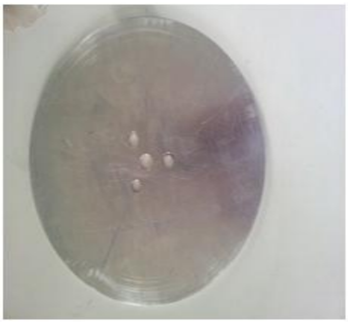

Figure 8 Aluminum disc

Figure 9 Mild steel disc

Making of mandrel for lathe:

- Initially cylindrical rod of measured diameter which that can be fit in lathe chuck.
- Then turning operation is done on that cylindrical specimen.
- Then step turning operation is done for a length of 4 mm and diameter 10mm.
- This making is important because unless until without mandrel disc skips and will not rotate as per the rated rpm.

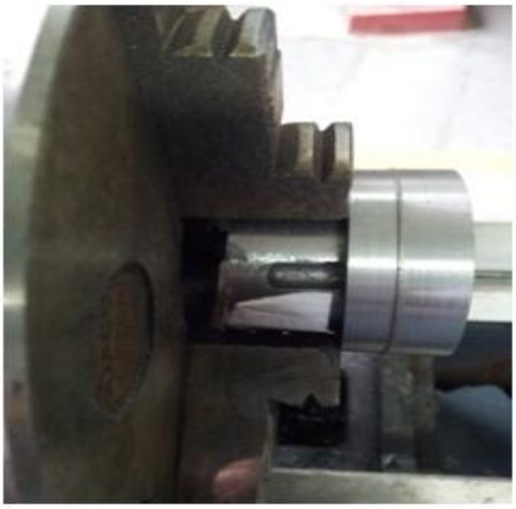

Figure 10 Mandrel assembly

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Figure 11 Mandrel

Figure 12 Square rod in tool post

Figure 13 Brake pad arrangement

Calculations:

properties	Aluminum	Mild steel
Mass	0.279 kg	1 kg
Specific heat cp in KJ/kg.k	0.921	0.42
Heat transfer coefficient(h)$W/m^2.k$	14	14
Density kg/m3	2800	7850
Thermalconductivity W/m.k	205	43
Rpm	1000	1000
Angular velocity(ω) rad/s	104.719	104.719
Mass moment of inertia(kg.m2)	$I=mr^2/2$	$I=mr^2/2$
Kinetic Energy (J)	$KE=0.5\ I\ \omega^2$	$KE=0.5I\ \omega^2$

At different radii in mm	Temperature distribution for Aluminum in °C	Temperature distribution for Mild steel in °C
100	43	37.9
95	42.6	38
90	41.33	32.6
85	40.2	31.5
83	39	30

ADVANTAGES BY USING ALUMINUM ALLOY

Durability

One of the key advantages of aluminum brake discs is durability. Aluminum is strong and resists corrosion and rusting, even over extended periods of time. After long periods of use, aluminum brake discs can be machined to restore a smooth surface, allowing them to be used for longer than brake discs made from other materials.

Weight

Another major advantage of aluminum brake discs is that they are light. According to Michigan Tech's Institute of Materials Processing, a car equipped with aluminum discs can weigh up to 11.3kg. less than a car that has traditional steel discs. This reduced weight can lead to better performance, faster acceleration, and shorter stopping distance. Less weight also means better fuel economy aluminum brake discs can save drivers between three and eight gallons of gas a year.
Aluminum discs are also less costly to transport and ship because they weigh less, saving manufacturers and retailers money over conventional, heavier brake discs.

Heat Dissipation

Aluminum brake discs dissipate heat better than steel discs do. This prevents too much heat from building up on the surface of the disc as localized heat generation where it can damage the brake pads or prevent the brakes from working properly. The localized heat can cause warping or distortion and dissipation is important to overall vehicle safety, as well as to the durability of the entire braking system.

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RESULTS AND ANALYSIS

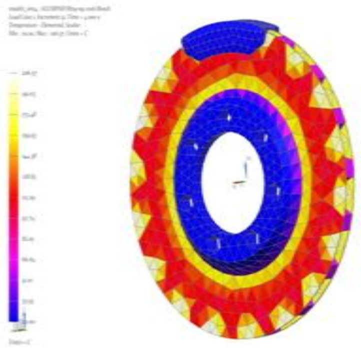


Figure14 shows temperature distribution for Al

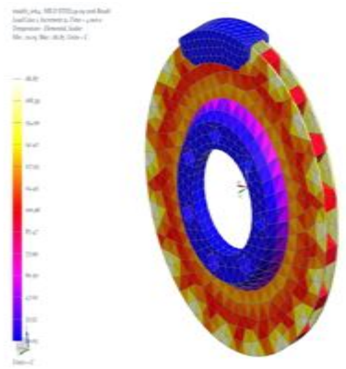


Figure 15 shows temperature distribution in MS

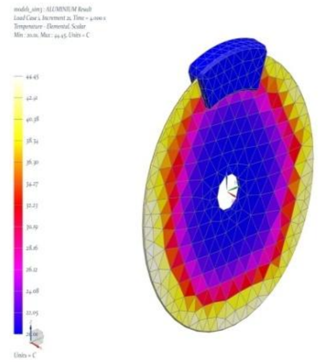


Figure16 shows temperature distribution for Al

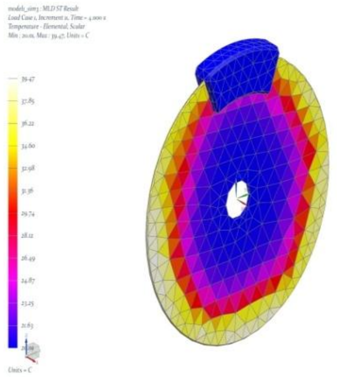


Figure 17 shows temperature distribution in MS

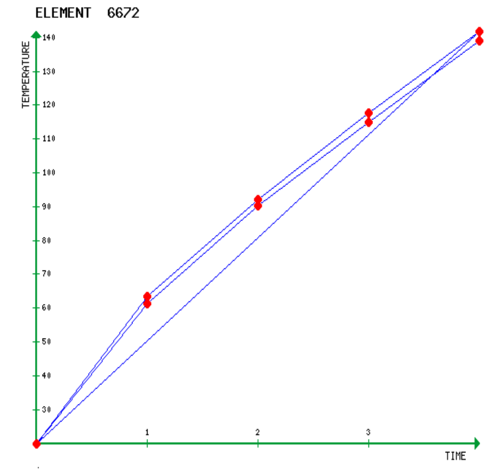


Figure 18 Al vs MS for 6672 element

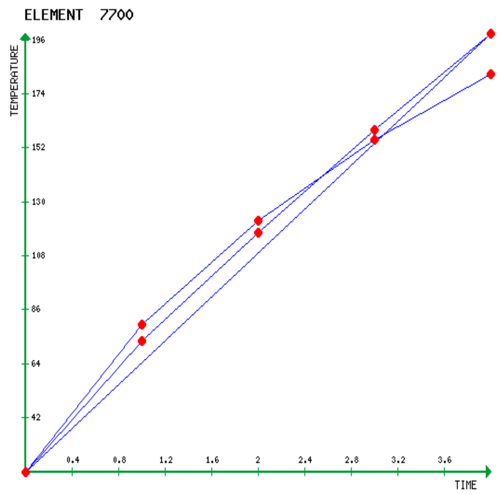
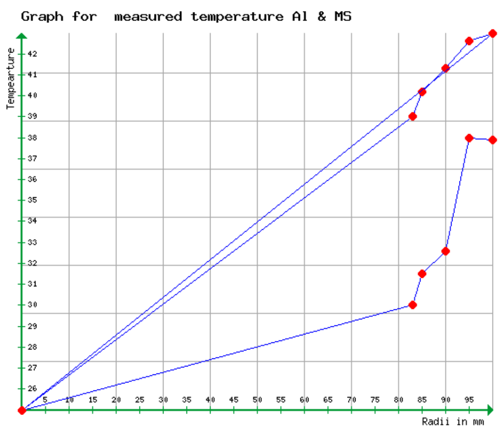


Figure 19 Al vs MS for7700 element

Graph for experimental values for 3mm thickness disc.



CONCLUSION

The maximum value in the temperature distribution of Aluminum is around 206oC.and maximum value in the temperature distribution of Mild steel is 189oC.The graph are drawn for different elements in meshing regarding temperature vs time .By using aluminum alloy for disc brakes the total weight of vehicles is reduced due to its low density and high strength. The moment of inertia of disc is reduced so that pick up acceleration of the vehicle increases and amount of fuel usage got reduced so that it may play an important role in environmental factor. According to generalized experimental which was conducted on lathe machine for analysis the temperature distribution for Aluminum is 43oC and Mild steel is 39.47oC.

RESULTS

Material type for 24 mm thickness disc	Maximum temperature distribution in °C in Analysis	Maximum temperature distribution in °C Theoretical
Aluminum Alloy 2014	206.57	196.3
Mild steel	181.7	178

Material Type for 3 mm thickness disc	Maximum temperature distribution in °C in Analysis	Maximum temperature distribution in °C Experimentally.
Aluminum	44.45	43
Mild steel	39.47	38

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