Analysis of Brake Pads Using Different Materials

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Abstract- *Studying about alternate materials for brake pads is necessary as the asbestos brake pads causes the carcinogenic effects and these are phased out. There are so many alternatives for asbestos which are investigated from different journals. In this review paper, some of the most suitable environment friendly and best performed compositions are presented. Fibers made up of agricultural wastes like banana peels, palm kernel shells, palm wastes, rock wool, aramid fibers, flax fibersetc are studied. Different alternatives for filler materials, Different binders like phenolic resin, epoxy resin are also studied and its effect on the performance of brake pads are presented. Formulations that are made by varying compositions of filler, fiber, binder etc and possibility of replacing the existing formulations and its effect on the physical and tribological properties of the brake pad are studied.*

Keywords- Asbestos, Analysis of material, Brake pads, Brake Disc, Brake performance, Deformation.

I. INTRODUCTION

A brake is a device which inhibits motion. Most brakes use friction to convert kinetic energy into heat, though other methods of energy conversion may be employed. For example, regenerative braking converts much of the energy to electrical energy, which may be stored for later use. Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel. In automobiles friction brakes are commonly used. A friction brake is a type of an automotive brake that slows or stops a vehicle by converting kinetic energy into heat energy, via friction. The braking heat is stored in the brake drum or disc while braking, then conducted to the air gradually.

In today's growing automotive market the competition for better performance vehicle is growing enormously. The function of the braking system is to retard the speed of the moving vehicle or bring it to rest in a shortest possible distance whenever required. The vehicle can be held on an inclined surface against the pull of gravity by the application of brake. Brakes are mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheels. It absorbs either kinetic energy or potential energy or both while remaining in action and this absorbed energy appears in the form of heat. While moving down a steep gradient the vehicle is controlled by the application of brakes. In this case brakes remain in action for a longer period making it imperative to dissipate the braking heat to atmosphere as rapidly as possible.

Automobiles are fitted with two brakes; the service or foot brake and the emergency or hand brake. The foot brake is used to control the speed of the vehicle and to stop it, when and where desired, by the application of force on the brake pedal. The hand brake, applied by a lever, is used to keep the vehicle from moving when parked. Hand brakes are called emergency brakes because they are applied when the service brake fails. Virtually all vehicles are now equipment with 4-wheel brakes. The front brakes must operate without interfering with the steering action.

The brakes must be capable of decelerating a vehicle at a faster rate than the engine is able to accelerate it. Normally brakes must absorb three times the amount of engine horsepower energy in its equivalent form. The disc brake is a device used for slowing or stopping the rotation of the wheel. A brake is usually made of cast iron or ceramic composites include carbon, aluminium, Kevlar and silica which is connected to the wheel and axle, to stop the vehicle. A friction material produced in the form of brake pads is forced mechanically, hydraulically, pneumatically and electromagnetically against the both side of the disc. This friction causes the disc and attached wheel to slow or to stop the vehicle. The methods used in the vehicle are regenerative braking system and friction braking system. A friction brake generates the frictional force in two or more surfaces rub against to each other, to reduce the movement. Based on the design configurations vehicle friction brakes are grouped into disc brakes and drum brakes. Our project is about disc brakes modelling and analysis.

The kinetic and potential energies of a moving vehicle get converted into thermal energy through friction in the brakes, during braking. The heat generated between the brake pad & disc must be dissipated by passing air over them. This heat transfer takes place by conduction, convection and somewhat by radiation. To achieve proper cooling of the disc and the pad by convection, study of the heat transport phenomenon between disc, pad and the air medium is necessary. Then it is important to analyse the thermal performance of the disc brake system to predict the increase in temperature during braking. Convective heat transfer model has been developed to analyse the cooling performance. Brake discs are provided with cuts to increase the area coming in contact with air and improve heat transfer from disc.

Modern cars have disc brakes with rotating discs being squeezed between two brake pads by the action of a hydraulic calliper. This turns a cars momentum into large amounts of heat and light, hence why Formula One brake discs often glow red hot. In the same way that too much power applied through a wheel will cause it to spin, too much braking will cause it to lock as the brakes overpower the available levels of grip from the tyre Formula One previously allowed anti-skid braking system but these were banned in 1990’s. Braking therefore remains one of the sternest tests of a Formula One driver’s skill, and an area in which he can make or lose a significant amount of time.

The technical regulations require that each car has a twin-circuit braking system with two separate reservoirs for the front and the rear wheels. This ensures that, even in the event of one complete circuit failure, braking should still be available through the second circuit. The amount of braking power going on the front circuit and the rear circuits can be biased by a control in the cockpit, allowing a driver to stabilize handling or take account of failing fuel load. In one area F1 brakes are empirically more advanced than road-car systems: materials. All the cars on the grid now use carbon fibre composite brake discs which save weight and are able to operate at higher temperatures than the steel discs. A typical Formula One brake disc weighs about 1.5 kg. These are gripped by special compound brake pads and are capable of running at vast temperatures – anything up to 750 degrees Celsius. As such a huge amount of efforts is put into developing brake ducts which not only provides sufficient cooling but which are also aerodynamically efficient.

Speaking of the efficiency, Formula One brakes are remarkably efficient. In combination, the modern advanced tyre compounds they have dramatically reduced braking distance. It takes a Formula One car considerably less distance to stop from 160kmph than a road car uses to stop from 100kmph. So, good are the brakes that the regulations deliberately discourage development through restrictions on materials or designed, to prevent even shorter braking distance rendering overtaking all but impossible?

The brake system on a Formula One car isn’t just responsible for scrubbing of speed – It’s also responsible for providing additional power, in as much as kinetic energy generated under braking is converted in electrical energy and return to the power train by the cars sophisticated energy recovery system(ERS). Since 2014, teams have been allowed to implement electronically control rear brake systems so that the drivers are able to maintain a reasonable level of balance and stability under braking.

II. LITERATURE REVIEW

1. **SAE recommended practice (SAE J880a) (1985) [1]**, recommends the performance requirements for motor cycles and motor driven vehicles. The recommended parameters and their values are either taken as the input data for this work or the performance parameters obtained as results and compared.
2. **AbdRahim Abu-Bakar, et al. (2005) [2]** This paper studies the contact pressure distribution of solid disc brake as a result of structural modifications. Before modifications are simulated, four different models of different degrees of complexity for contact analysis are investigated. It is shown that the contact pressure distributions obtained from these four models are quite different. This suggests that one should be careful in modelling disc brakes in order to obtain correct contact pressure distributions. This work could help design engineers to obtain a more uniform pressure distribution and subsequently satisfy customers’ needs by making pad life longer.
3. **M. Nouby, et al. (2009) [3]** proposes an approach to investigate the influencing factors of the brake pad on the disc brake squeal by integrating finite element simulations with statistical regression techniques. Complex Eigen value analysis (CEA) has been widely used to predict unstable frequencies in brake systems models. The finite element model is correlated with experimental modal test. The ‘input-output’ relationship between the brake squeal and the brake pad geometry is constructed for possible prediction of the squeal using various geometrical configurations of the disc brake. Influences of the various factors namely; Young’s modulus of back plate, back plate, thickness, Chamfer. Distance between two slots, slot width and angle of slot are investigated using design of experiments (DOE) technique. A mathematical prediction model has been developed based on the most influencing factors and the validation simulation experiments proved its adequacy.
4. **P. Liu a, et al. (2007) [4]** An attempt is made to investigate the effects of system parameters, such as the hydraulic pressure, the rotational velocity of the disc, the

friction coefficient of the contact interactions between the pads and the disc, the stiffness of the disc, and the stiffness of the back plates of the pads, on the disc squeal. The simulation results show that significant pad bending vibration may be responsible for the disc brake squeal. The squeal can be reduced by decreasing the friction coefficient, increasing the stiffness of the disc, using damping material on the back plates of the pads, and modifying the shape of the brake pads.

5 **R. G. Choudhari, (2011) et al. [5]**FEM model is prepared for contact analysis. A three-dimensional finite element model of the brake pad and the disc is developed to calculate static structural analysis, and transient state analysis. The comparison is made between the solid and ventilated disc keeping the same material properties and constraints and using general purpose finite element analysis. This paper discusses how general purpose finite element analysis software can be used to analyse the equivalent (von-mises) stresses& the thermal stresses at disc to pad interface.

6 **H Mazidi, et al. (2011) [6]** In this study, the heat conduction problems of the disc brake components (Pad and Rotor) are modelled mathematically and is solved numerically using finite difference method. In the discretization of time dependent equations, the implicit method is considered. In the derivation of heat equations, parameters such as the duration of braking, vehicle velocity, Geometries and the dimensions of the brake components, Materials of the disc brake rotor and the PAD and contact pressure distribution have been taken into account.

7 **V.M.M.Thilak, et al. (2011) [7]**In this work, an attempt has been made to investigate the suitable hybrid composite material which is lighter than cast iron and has good Young’s modulus, Yield strength and density properties. Aluminium base metal matrix composite and High Strength Glass Fibre composites have a promising friction and wear behaviour as a Disk brake rotor. The transient thermo elastic analysis of Disc brakes in repeated brake applications has been performed and the results were compared. The suitable material for the braking operation is S2 glass fibre and all the values obtained from the analysis are less than their allowable values.

8 **PrashantChavan, (2006) et al. [8]** Gives simplified yet almost equally accurate modelling and analysis method for thermo-mechanical analysis using brake fade test simulation as an example. This methodology is based on use of ABAQUS Axisymmetric analysis technique modified to represent effect of discrete bolting, bolt preloads, and contacts within various components of the assembly.

9 **Q Cao1, et al. (2003) [9]** This paper presents a numerical method for the calculation of the unstable frequencies of a car disc brake and the analysis procedure. The stationary components of the disc brake are modelled using finite elements and the disc as a thin plate. This approach facilitates the modelling of the disc brake squeal as a moving load problem. Some uncertain system parameters of the stationary components and the disc are tuned to fit experimental results. A linear, complex-valued, asymmetric Eigen value formulation is derived for disc brake squeal. Predicted unstable frequencies are compared with experimentally established squeal frequencies of a realistic car disc brake.

10 **S. P. Jung, et al. (2010) [10]**A simple finite element model of a disc and two pads was created, and TEI phenomenon was implemented by rotating the disc with a constant rotational speed of 1400 rpm. The intermediate processor using the staggered approach was used to connect results of two other analysis domains: mechanical and thermal analysis. By exchanging calculation results such as temperature distribution, contact power and nodal position at every time step, solutions of fully coupled thermo-mechanical system could be obtained. Contact pressure distribution of the pad surface was varied according to the rotational direction of the disc. DTV and temperature of the disc were calculated and tendency was verified by earlier studies.

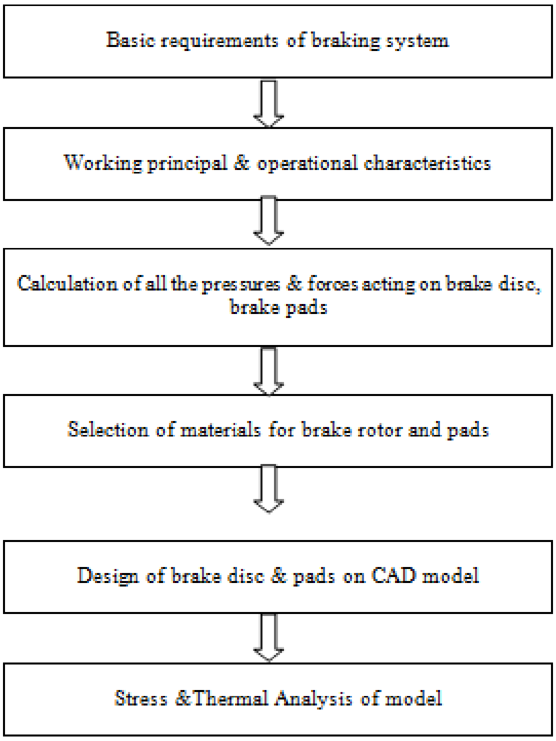
III. OBJECTIVES

1. The main objective of Automobile Brake System is to slow down or stop a vehicle in a shortest possible distance safely.
2. It should be able to convert kinetic energy into heat energy and dissipate it quickly.
3. To select the best pair material for brake disc and brake pad.
4. To find speed and torque which generate at a time of running of engine.

IV. PROPOSED METHODOLOGY

Brake pads are important parts of braking system for all types of vehicles that are equipped with disc brake. Brake pads are steel backing plates with friction material bound to the surface facing the brake disc. We are using different materials for pads like asbestos, metallic, semi metallic, ceramic and then analysed. We are showing which brake pad are effective for braking.

During the brake disc design, it is necessary to consider different subjects like geometry, weight, material, maximum work temperature, crack resistance, thermal distortions, casting, noise, etc. All this subjects must be included in an appropriate design methodology:



V. THE BASIC PRINCIPLE & OPERATION OF SYSTEM

When the driver pushes the brake pedal force will be transmitted to the piston in the master cylinder. The pistons will apply the pressure to the fluid in the cylinder and the brake lines transfer the pressure to the calliper. The pistons in the hydraulic cylinder in the calliper are move to apply the brakes.

When disc brake is applied, brake pad is clamped against the disc. A moving vehicle has energy, which must be absorbed by the brakes when they are applied. The energy is converted into heat because of the friction between the breaking surfaces. The heat is then dissipated into the brake parts and into the surrounding atmosphere. Therefore, the brake pad and disc or the brake lining, the material must be withstood high temperature as well as high pressure.

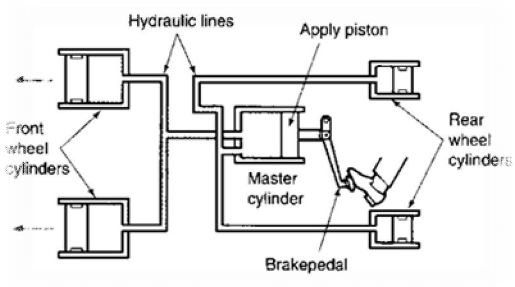


Fig1:Basic Operation Of Hydraulic Disc Brake

The hydraulic system (Fluid Power) is a method of transmitting the motion or force. It does this by having a cylinder and piston in a different size. Hydraulic is based on the fact that liquid can flow easily through complicated path, yet cannot be compressed. Another important feature is that when liquid transmit pressure, that pressure will be transmitted equally in all direction. This is known as Pascal's Principle.

VI. SELECTION OF MATERIALS FOR BRAKE ROTOR AND PADS

The Disc brake discs are commonly manufactured out of grey cast iron. The SAE maintains a specification forth manufacture of grey iron for various applications. For normal car and light truck applications, the SAE specification is J431 G3000 (superseded to G10). This specification dictates the correct range of hardness, chemical composition, tensile strength, and other properties necessary forth intended use. Some racing cars and airplanes use brakes with carbon fibre discs and carbon fibre pads to reduce weight. Wear rates tend to be high, and braking may be poor or grabby until the brake is hot. The materials used for Brake pad are explained in detail. It is investigated deformation, and the stress of automotive brake pad has quite close relations with car safety; therefore, much research in this field has been performed

Table:1Brake Materials Properties

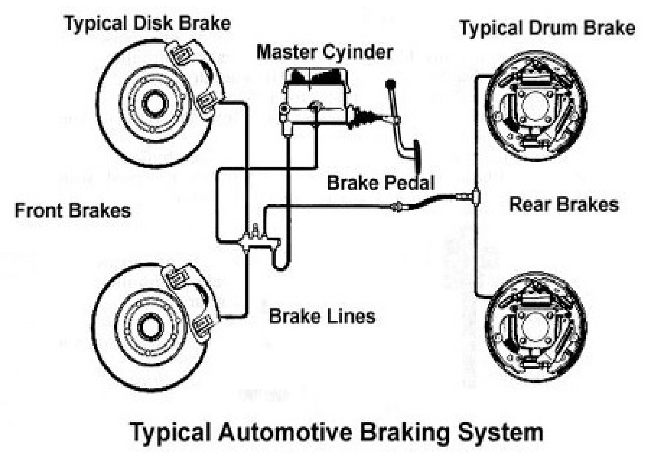
Material Properties	Carbon Fibre	Asbestos	Gray Cast Iron	Palm Kernel Shell
Thermal Conductivity (W/mK)	4	0.539	54	1.46
Density (kg/m^3)	2500	1890	7100	1650
Thermal Expansion Coefficient (K^{-1})	4.25×10^{-6}	4.25×10^{-6}	12×10^{-6}	10.49×10^{-5}
Specific Heat Capacity (J/kgK)	1060	1344	586	1907
Friction Coeff	0.27	0.3	0.25	0.43
Young's Modulus (GPa)	226	120	125	553
Poisson Ratio	0.3	0.28	0.24	0.4
Tensile Strength (MPa)	2550	3500	2400	6.8

Table:2 Material properties of a disc brake rotor

Material Properties	Gray Cast Iron
Thermal Conductivity (W/mK)	54
Density (kg/m^3)	7100
Thermal Expansion Coefficient (K^{-1})	12 x 10^{-6}
Specific Heat Capacity (J/kgK)	586
Friction Coeff	0.25
Young's Modulus (GPa)	125
Poisson Ratio	0.24
Tensile Strength (MPa)	2400

VII. BASIC PARTS OF BRAKE SYSTEM

1. Pad, Caliper and Disc - Slow or stop the wheels when the brake callipers at the wheel.
2. Brake Pedal - Operated by the driver.
3. Master cylinder - Provides hydraulic pressure
4. Brake lines and Hoses - Connect the master cylinder to the calliper at the wheels
5. Brake Fluid - Transmits force from the mastercylinder to the Calipers at the wheels.



VIII. DESIGN AND BASIC CALCULATION

Finite Element Model:

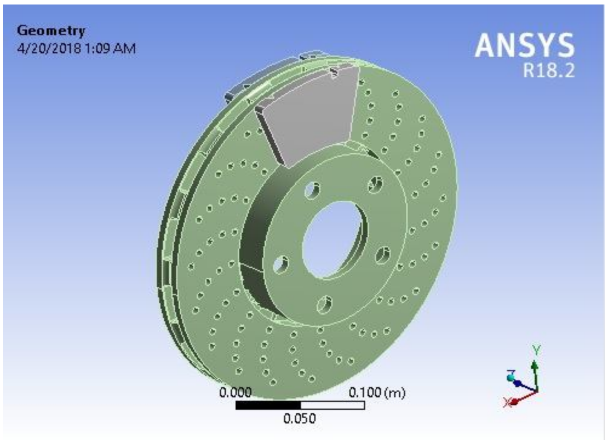


Fig. 3: Model Creation on Ansys

The first step was to prepare a structure model of the brake disc with pads. This was carried out using finite element software (Fig. 3). Then it was meshed and defined by boundary conditions to put on ANSYS Multiphysics and to initialize the calculation. In this work, a three-dimensional FE model consists of a ventilated disc and two pads as illustrated in Fig.4

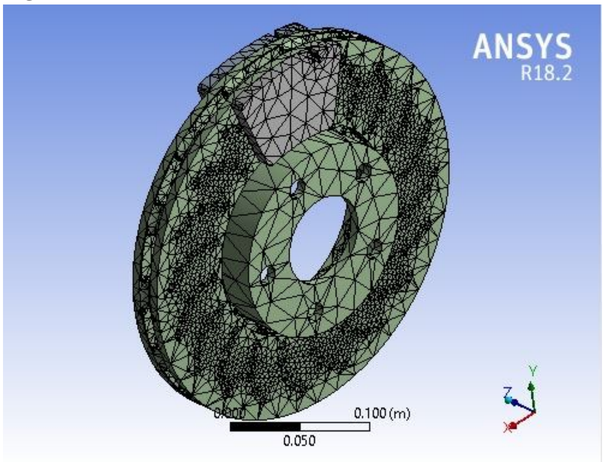


Fig. 4: Mesh of FE model of Disc Pad Assembly

Determination of Hydraulic Pressure:

Nomenclature:

F_d = Force on the disc
R_t = Radius of tire
R_r = Radius of rotor
R_2 = Outer Radius of the pad
R_1 = Inner Radius of the pad
t_s = time taken to stop the automobile
v = initial speed
v = $\sqrt{\mu g d}$ m/s
Stopping distance: $\frac{v^2}{2a}$

Rotational Speed (ω) = $\frac{v}{R_t}$

Force on the disc = $F_{disc} = \frac{(30\%)*\frac{1}{2}mv^2}{2*\frac{R_r}{R_t}\left(v.t_s\frac{1}{2}\left(\frac{v}{t_s}\right)*.t_s^2\right)}$

$P = \frac{F_{disc}}{A_c*\mu}$

Boundary conditions and loading on Disc and Pads:

In this FE model, boundary conditions in embedded configurations are imposed on the models (disc-pad) as shown in Fig. (5) for applied pressure on both sides of the pad. The disc is rigidly constrained at the bolt holes in all directions except in its rotational direction. Meanwhile, the pad is fixed at the abutment in all degrees of freedom except in the normal direction to allow the pads move up and down and in contact with the disc surface.

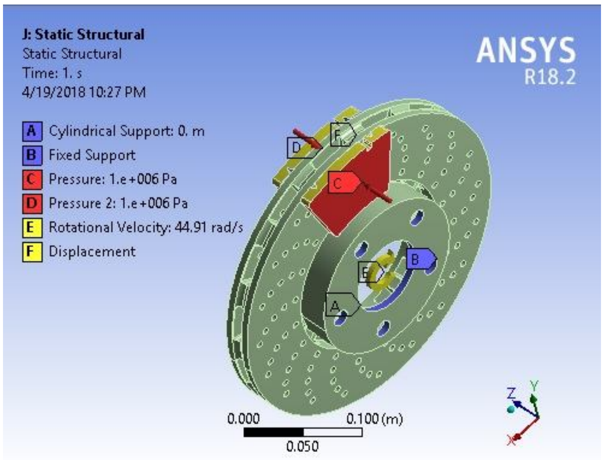


Fig. 5: Boundary conditions and loading on Disc and Pads

VIII. COMPONENT PROPERTIES

Design of disc brake

Rotors are made of Grey cast iron for three reasons

- It is relatively hard and resists wear.
- It is cheaper than steel or aluminium.
- It absorbs and dissipates heat well to cool the brakes.

<u>Material: Grey Cast Iron</u>

Outer disc diameter:	280 mm	
Disc thickness	:	24 mm
Disc hole diameter	:	8 mm
Pad thickness	:	10 mm
Mass of the disc	:	7 kg

Material properties of Disc

Properties		Grey Cast Iron
Density	-	7100
Young's Modulus (GPa)	-	125
Poisson Ratio	-	0.25
Thermal Conductivity (W/M-K)	-	54.5
Specific Heat (J/Kg-K)	-	586
Coefficient of Friction	-	0.2

IX. RESULTS OF MECHANICAL CALCULATION

The computer code ANSYS also allows determination and visualization of the structural deformations due to the sliding contact between the disc and the pads. The results of calculations of contact described in this section is related to the displacements or the total deformation during the loading sequence, the field of equivalent stresses Von Mises on the disc, and the contact pressures of inner and outer pad at different braking period.

Pad Deformation:

Fig. 6 shows Pad deformations for different material. Following Fig. shows the deformation in Asbestos, Grey Cast iron, Carbon Fibre and Palm Kernel Shell Pads. It is shown by the tag the Maximum and Minimum deformation occurrence in the pad for the application of same force in all the cases of different material.

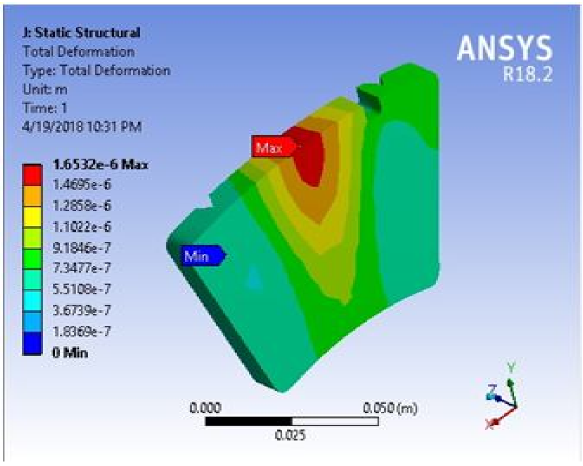


Fig (a). Grey Cast Iron

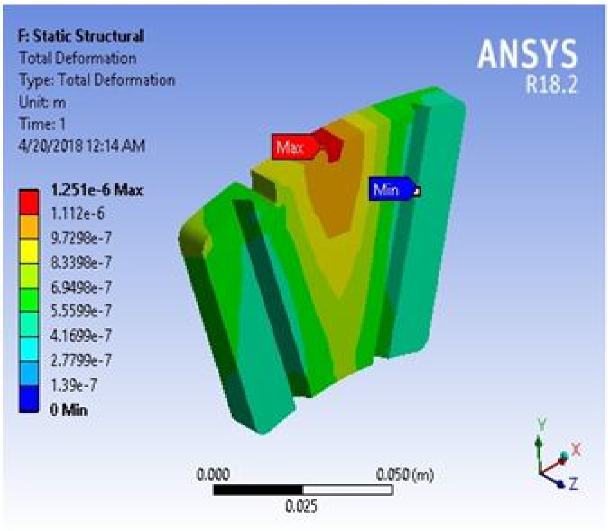


Fig (b). Asbestos

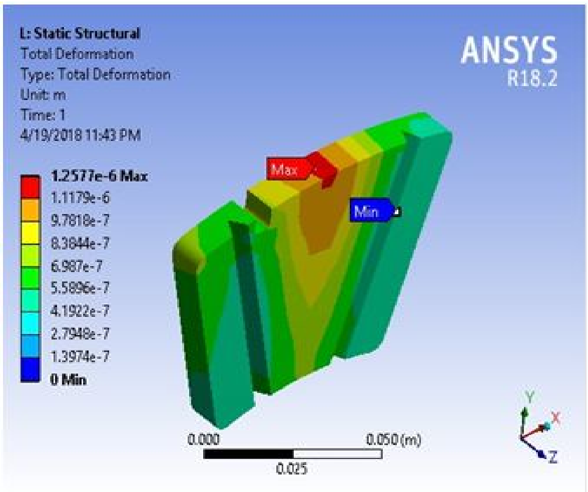


Fig (c):Carbon Fibre

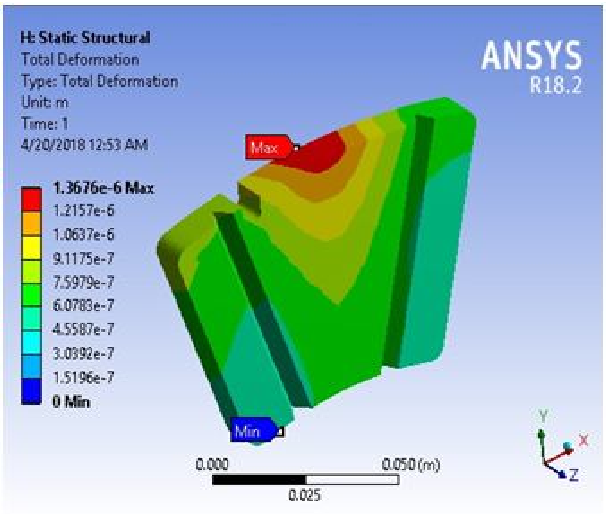


Fig (d). Palm Kernel Shell
Fig. (6). Deformation of Different Pad Materials

It can be seen that the minimum deformation occurs in the material asbestos 1.251e^{-6}

While the maximum deformation occurs in the material Grey Cast Iron 1.6532e^{-6}. The huge deformation is located at the outer radius region (visualized in the red colour) as depicted in Fig. (6)

Stress distribution on the pads

From Fig. (7), it can be observed that the equivalent Von Mises stress is distributed at almost same area for different material. These stress distributions are barely unchanged over braking time except the stress value. It shows that the stress increases gradually and it reaches its maximum value of 1.1293e7

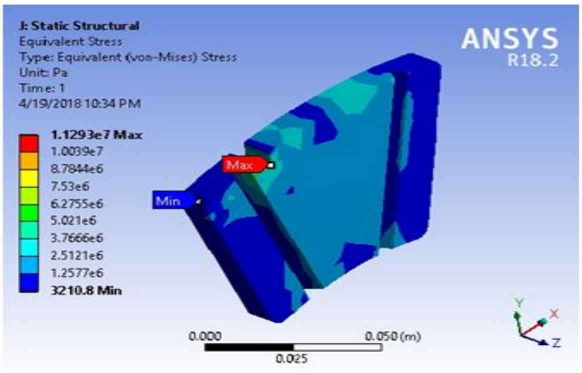


Fig (a). Grey Cast iron

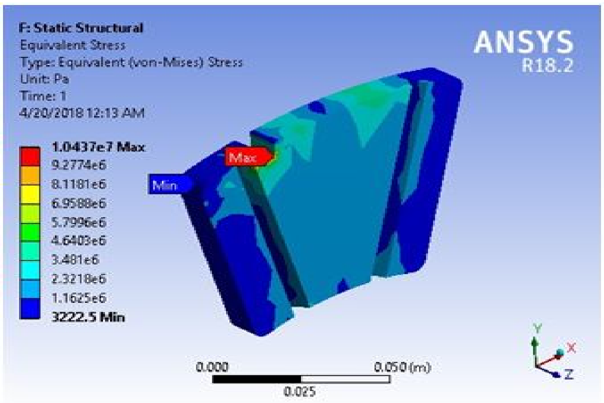


Fig (b).Asbestos

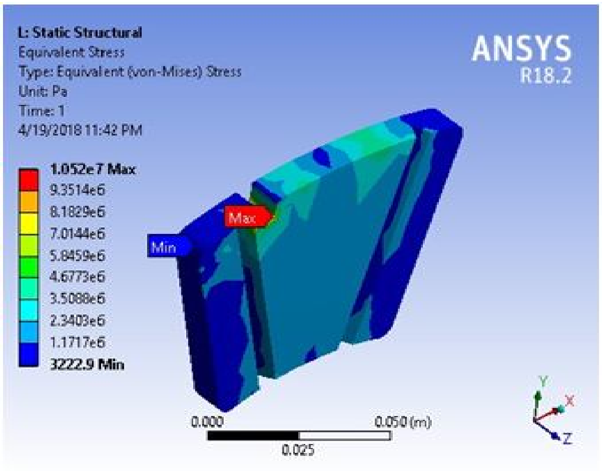


Fig (c). Carbon Fibre

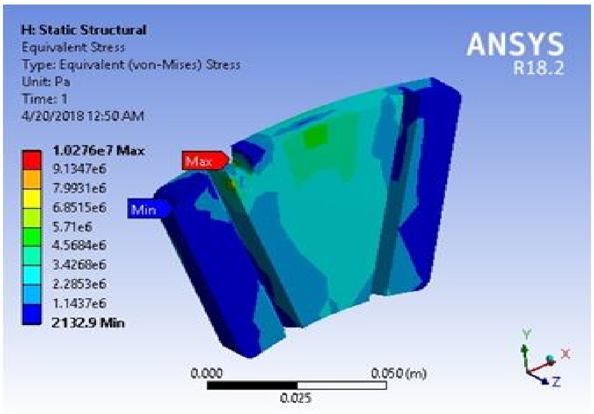


Fig (d). Palm Kernel Shell

Fig. (7). Stress Distribution on Different Pad Materials

It can be observed from the above fig. that the maximum equivalent Von Mises stress occurs in Grey cast iron pad whereas the minimum occurs in Palm Kernel Shell Pads.

V. CONCLUSION

Final conclusion about the project is that to find a replacement for Asbestos as a Brake pad material.

With this project, we analysed different material for brake pads to find a durable and viable material for brake pads in a disc brake system taking in consideration all the forces exerted from every component in the brake system. In our analysis for the Static calculation approach we found that the deformation of various materials for same amount of force differs very less from one another. With this we demonstrate that we have a viable replacement for asbestos theoretically. Experimental study to verify the accuracy of the numerical model developed; also, the smoothness of the mesh increases the precision of the solution. The results obtained for the numerical calculation are comparable with those which one finds in the specialized literature.

REFERENCES

[1] Piotr GRZEŚ, Finite Element Analysis of DiscTemperature During Braking Process, Faculty of Mechanical Engineering, Białystok TechnicalUniversity, ul. Wiejska 45 C, 15-351 Białystok (2010).

[2] M. Nouby, D. Mathivanan, K. Srinivasan, acombined approach of complex eigenvalue analysisand design of experiments (DOE) to study disc brake squeal, International Journal of Engineering,Science and Technology Vol. 1, No. 1, 2009, pp.254-271.

[3] P. Liu a, H. Zheng a, C. Cai a, Y.Y. Wang a, C.Lu a,K.H. Ang b, G.R. Liu, Analysis of disc brakesqueal using the complex eigenvalue method,ScienceDirect, Applied Acoustics 68 (2007) 603–615.

[4] RajendraPohane, R. G. Choudhari, Design andFinite Element Analysis of Disc Brake,International J. of Engg. Research &Indu. Appls.(IJERIA). ISSN 0974-1518, Vol.4, No. I (February2011), pp 147-158.

[5] H Mazidi, S.Jalalifar, J. Chakhoo, MathematicalModel of heat conduction in a disc brake systemduring braking, Asian journal of Applied Science4(2): 119-136,2011, ISSN 1996-3343 / DOI:10,3923/ajaps,2011,119,136.

[6] V.M.M.Thilak,RKrishnaraj, Dr.M.Sakthivel,K.Kanthavel, DeepanMarudachalamM.G,R.Palani , Transient Thermal and StructuralAnalysis of the Rotor Disc of Disc Brake ,International Journal of Scientific & EngineeringResearch Volume 2, Issue 8, August-2011 ISSN2229-5518.

[7] PrashantChavan, AmolApte, Axisymmetricanalysis of bolted disc brake assembly to evaluatethermal stresses TATA motors ltd. Pimpri, Pune-411018. India 91-20 5613 3159.

[8] Q Cao1, M I Friswell, H Ouyang, J EMottershead1 and S James, Car Disc Brake Squeal: Theoretical and Experimental Study Materials Science Forum Vols. 440-441 (2003) pp.269-276 © (2003) Trans Tech Publications,Switzerland.

[9] S. P. Jung, T. W. Park, J. H. Lee, W. H. Kim, andW. S Chung, Finite Element Analysis ofThermoelastic Instability of Disc Brakes,Proceedings of the World Congress on Engineering2010 Vol II WCE 2010, June 30 - July 2, 2010, London, U.K.

[10] Huajiang Ouyang, Wayne Nack, Yongbin Yuan,Frank Chen, Numerical analysis of automotivedisc brake squeal, Int. J. Vehicle Noise andVibration, Vol. 1, Nos. 3/4, 2005.

[11] Hao Xing, Squeal Analysis of Disc Brake System,Beijing FEAonline Engineering Co.,Ltd. Beijing,China, 4th ANSA & μETA InternationalConference.

[12] A Söderberg, U Sellgren, S Andersson, Usingfinite element analysis to predict the brake pressureneeded for effective rotor cleaning in disc brakes, 2008-01-2565.

[13] Abd Rahim Abu-Bakar, Huajiang Ouyang, RecentStudies of Car Disc Brake Squeal, In: NewResearch on Acoustics ISBN 978-1-60456-403-7 ,pp.159-198 © 2008 Nova Science Publishers, Inc.

[14] Swapnil R. Abhang , D.P Bhaskar , Design and Analysis of Disc Brake , International Journal of Engineering Trends and Technology (IJETT) – Volume 8 Number 4- Feb 2014.

[15] V.M.M Thilak , R.Krishnaraj , Dr.M.Sakthivel, K.Kanthavel, DeepanMarudachalamM.G, R.Palani , Transient Thermal and Structural Analysis of the Rotor Disc of Disc Brake , International Journal of Scientific &Engineering Research Volume 2, Issue 8, August -2011.

[16] D Chan and G W Stachowiak , Review of automotive brake friction materials , School of Mechanical Engineering, University of Western Australia , Crawley , Australia june 2009.

[17] M.O. Petinrin, John Ogheneortega Oji Numerical Simulation of Thermoelastic Contact Problem of Disc Brake with Frictional Heat Generation.WCEJuly 2, 2010, London, U.K.